The Association of Engineering and Shipbuilding Draughtsmen.

Modern Rubber, Synthetic Rubber, and Thermoplastic Insulated Cables.

By C. C. BARNES, Hons. Dipl., C.G.L.I., A.M.I.E.E., A.I.I.A.

Published by The Association of Engineering and Shipbuilding Draughtsmen,
Onslow Hall, Little Green, Richmond, Surrey.

SESSION 1955-56.

Price 6/-

Printed by Milne, Tannahill & Methven, Ltd. (T.U.), 12-14 Mill Street, Perth.

ADVICE TO INTENDING AUTHORS OF A.E.S.D. PRINTED PAMPHLETS.

Pamphlets submitted to the National Technical Sub-Committee for consideration with a view to publication in this series should not exceed 10,000 to 15,000 words and about 20 illustrations. The aim should be the presentation of the subject clearly and concisely, avoiding digressions and redundance. Manuscripts are to be written in the third person. Copies of an article entitled "Hints on the Writing of Technical Articles" can be obtained from the Editor of *The Draughtsman*.

Drawings for illustrations should be done either on a good plain white paper or tracing cloth, deep black Indian ink being used. For ordinary purposes they should be made about one-and-a-half times the intended finished size, and it should be arranged that wherever possible these shall not be greater than a single full page of the pamphlet, as folded pages are objectionable, although, upon occasion, unavoidable. Where drawings are made larger, involving a greater reduction, the lines should be made slightly heavier and the printing rather larger than normal, as the greater reduction tends to make the lines appear faint and the printing excessively small in the reproduction. In the case of charts or curves set out on squared paper, either all the squares should be inked in, or the chart or curve should be retraced and the requisite squares inked in. Figures should be as self-evident as possible. Data should be presented in graphical form. Extensive tabular matter, if unavoidable, should be made into appendices.

Authors of pamphlets are requested to adhere to the standard symbols of the British Standards Institution, where lists of such standard symbols have been issued, as in the case of the electrical and other industries, and also to the *British Standard Engineering Symbols and Abbreviations*, No. 1191, published by the B.S.I. at 5/-. Attention might also be given to mathematical notation, where alternative methods exist, to ensure the minimum trouble in setting up by the printer.

The value of the pamphlet will be enhanced by stating where further information on the subject can be obtained. This should be given in the form of footnotes or a bibliography, including the name and initials of the author, title, publisher, and year of publication. When periodicals are referred to, volume and page also should be given. References should be checked carefully.

Manuscripts, in the first instance should be submitted to the Editor, *The Draughtsman*, Onslow Hall, Little Green, Richmond, Surrey.

For pamphlets, a grant of £20 will be made to the author, but special consideration will be given in the case of much larger pamphlets which may involve more than the usual amount of preparation.

The Publishers accept no responsibility for the formulae or opinions expressed in their Technical Publications.

The Association
of
Engineering and Shipbuilding
Draughtsmen.

Modern Rubber, Synthetic Rubber, and Thermoplastic Insulated Cables.

By C. C. BARNES, Hons. Dipl., C.G.L.I., A.M.I.E.E., A.I.I.A.

Published by The Association of Engineering and Shipbuilding Draughtsmen,
Onslow Hall, Little Green, Richmond, Surrey.

SESSION 1955-56.

4/56

MODERN RUBBER, SYNTHETIC RUBBER, and THERMOPLASTIC INSULATED CABLES.

By C. C. BARNES, Hons. Dipl., C.G.L.I., A.M.I.E.E., A.I.I.A.

INTRODUCTION.

Electric cables are the vital arteries by means of which energy is conveyed from the source of generation to the place where it is applied to useful work. The transmission and distribution of electrical energy is, for economic and technical reasons, carried out by means of oil impregnated paper insulated cables, but the wiring of factories, power stations, and domestic buildings is mainly carried out by means of rubber and/or thermoplastic insulated cables : these cables are reviewed in the following notes.

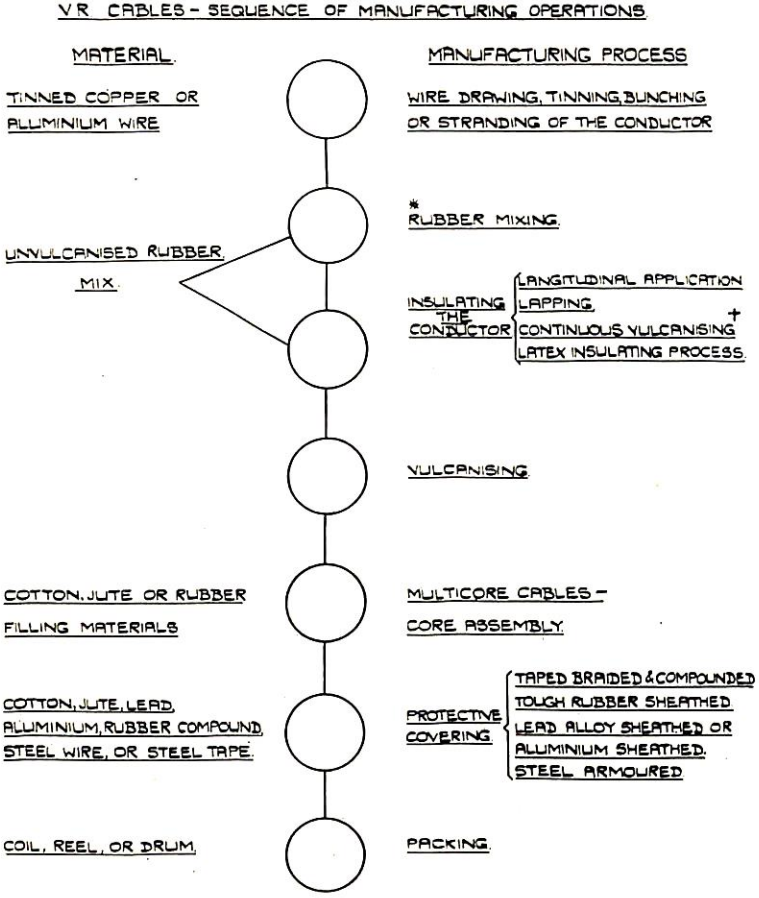
Considerable use is also made of rubber and thermoplastic cables for mining work, cabling of ships, aircraft, etc.

In the early days of cable making the manufacturer was obliged to rely on insulating materials from the commodities of commerce such as cotton and silk yarns, paper, bitumen, natural oils, gutta percha, amber and rubber, but the application of the chemistry of polymerisation and of complex molecules over the past decade or so are at the present time making available new materials which must ultimately produce a gradual revolution in cable design and construction. Developments in the past were limited by the availability of naturally occurring raw materials but the aim of the future is to synthesize materials having the exact properties required of them. This latter object is already being achieved in the field of thermoplastics (viz., Polyvinyl Chloride, Polythene, etc.).

In the following notes the different components of the insulated cables considered are reviewed under three separate but inter-dependent sections, *i.e.* :—

1. The Conductor.
2. The Dielectric (or Insulation).
3. Protective Finishes.

Figure No. 1 shows the sequence of manufacturing operations necessary for the production of the various types of vulcanised rubber insulated-cables.



* FROM THE RUBBER MIXER, THE RUBBER COMPOUND IS TRANSFERRED TO A SHEETING MILL WHICH CONVERTS IT TO SHEET RUBBER ABOUT 1/2" THICK. WHEN THE RUBBER IS TO BE APPLIED TO THE CONDUCTOR BY THE LONGITUDINAL METHOD IT IS FIRST ROLLED INTO THIN SHEETS ON A CALENDER & THEN CUT INTO NARROW ROLLS FOR APPLYING AROUND THE CONDUCTOR ON THE LONGITUDINAL INSULATING MACHINES.

† INSULATED AND VULCANISED IN ONE CONTINUOUS OPERATION.

Fig. 1.

SYNOPSIS.

For convenience the following data provided has been divided into sections as follows :—

1. The Conductor.
   - 1 (1) Standard Stranded Conductors.
   - 1 (2) Flexible Conductors.
2. Rubber Insulated Cables.
   - 2 (1) The Rubber Mix.
   - 2 (2) Physical Properties of the Insulation.
   - 2 (3) Electrical Properties of the Insulation.
3. Application of the Rubber Insulation to the Conductor(s).
   - 3 (1) The "Longitudinal" Method.
   - 3 (2) Lapping Method.
   - 3 (3) Continuous Vulcanisation (C.V.) Process.
   - 3 (4) The Latex Insulating Process.
4. Application of Proofed Tape over the Insulated Conductor. Vulcanising Process.
5. Protective Coverings.
   - 5 (1) Taped Braided and Compounded Finish (T.B. & C.).
   - 5 (2) Tough Rubber Sheathed (formerly Cab Tyre Sheathing).
   - 5 (3) Lead Alloy Sheathing.
   - 5 (4) Steel Armouring.
   - 5 (5) Aluminium Sheathing.
6. Ordering Specification and Tests.
7. Current Loading and Installation of V.R. Cables.
8. Synthetic Rubber-like Materials.
9. Polyvinyl Chloride (P.V.C.) Insulated Cables.
10. Polythene Insulated Cables.
11. Polystrene.
12. Nylon.

Useful References.

I. General.

II. Natural Rubber.

III. Synthetic Rubber-like Materials.

IV. Polyvinyl Chloride (P.V.C.).

V. Polythene.

APPENDICES.

1. Calculated Conductor Areas (Stranded Circular Conductors).
2. Persulphate Test for Tinned Copper Wire (B.S. 7—1953 Specification).
3. Conductors for Flexible Cables (B.S. No. 7—1953).
4. Conductors for Flexible Cords (B.S. No. 7—1953).
5. Comparative Diameters and Weights of British S.W.G. and American B. & S. Wire Gauges.
6. Solid and Stranded Circular Conductors to B.S. No. 7—1953.
7. Characteristics of Dielectrics.
8. Electricity Resistivity of the Metallic Components of Electric Cables.
9. Definitions of certain terms used in Cable Technology.
10. Summary of Principal British Standard Specification Relating to V.R. Insulated Cables.
11. Lead and Lead Alloys for Sheathing Cables.
12. Capacity of Conduits (250 Volt Grade Cables).
13. Computing Conductor Sizes.
14. Current for D.C. and A.C. Motors.
15. Thermal Classification of Insulating Materials.
16. Temporary Relaxation in Current Ratings of Small V.R., P.V.C., Paper and V.C. Cables for Wiring of Buildings.

1. THE CONDUCTOR.

The copper conductor is drawn in copper rolling mills from ingots or wire bars and it usually starts in the cable factory in the form of $\frac{1}{4}$" diameter refined copper rods. These rods are then passed through a bath of dilute acid which dissolves off the black surface film of oxide which the previous hot rolling process leaves on the rods. The rod is then passed through a series of tungsten carbide steel dies in a wire drawing machine which in one operation reduces the $\frac{1}{4}$" diameter rod down to 0·052" or 0·044" diameter wire (refer Appendix No. 1 for data on the standard range of annealed circular stranded conductors).

Following the drawing operation, the hard drawn copper wire produced is given a period of heat treatment in an annealing furnace which removes the springiness out of the hard drawn wire and provides the ductility necessary for the subsequent processing, and the final performance of the finished cable.

During the whole of the process of working the copper, and particularly during the final annealing, precautions have to be taken both to prevent the formation of oxide on the surface and also its inclusion in the wire. The annealing process is carried out in a completely non-oxidising atmosphere obtained either by the complete exclusion of air from the annealing furnace or by replacing the air with an inert gas. In the case of the smaller diameter wires a further drawing operation is necessary after the annealing process. For this operation diamond dies are employed by which means it is possible to reduce the wire diameter to the fine gauge necessary for flexible cords, some of which are made with 0·0076" or even 0·002" diameter wires.

High conductivity standard annealed copper conductors are to-day a very consistent product, but two factors require careful consideration, *i.e.*, uniformity in drawing and (where required) tinning operations. In the wire drawing operation it is essential to obtain uniform gauge along the length in order to comply with the specified limits of resistance and the conductor surface must be free from defects which may impair the subsequent tinning operation.

Copper exposed to sulphur (which may be used in the rubber mix) becomes corroded and the resultant copper oxide and its salts have a peculiar and definite accelerating effect on the perishing of rubber, therefore, an effective coating of tin is necessary to separate the copper from direct contact with the rubber.

During the war material shortages led to the use of a tin/lead eutectic alloy for protecting the copper conductor, but the pre-war practice of using a pure tin coating has now been re-introduced. The tinning operation must be such as to produce uniformity in the thickness of tin coating, smoothness of surface, and most important,

absence of porosity or uncovered places. These requirements are met by appropriate tests (see Appendix 2).

In the past the classical method of assessing the quality of tinning was the so-called polysulphide test. This test is based on the chemical fact that copper, in the presence of sulphur, will blacken. When carrying out the test the wire under examination is wound into a helix, the diameter of which bears a definite relation to the diameter of the test sample. After degreasing, the wire is dipped for a definite period into hydrochloric acid, washed in water and then in sodium polysulphide for specified cycles of treatment. This test is of doubtful value because it provides a measure of the thickness of tin coating rather than its conductivity.

An important test now specified (refer to Appendix No. 2) is the persulphate test, which depends on the fact that copper in the presence of ammonia develops a very deep blue solution. For the persulphate test the mandrel diameter, method of cleaning the specimen, and method of immersion of the test sample are carefully defined. At any points where the tinning is faulty copper is dissolved from the wire by the persulphate reagent and the quality of the tinning on the wire is expressed by the amount of copper dissolved from a known area of exposed surface.

From the depth of the blue colour it is possible to compute the amount of copper which has been dissolved—this weight is expressed as milligrammes of copper per square decimetre of wire immersed.

1 (1) Standard Stranded Conductors.

Single wire conductors, usually 1/·036″ (0·001 sq. in.), 1/·044″ (0·0015 sq in.) and 1/·064″ (0·0030 sq. in.) are used to a limited extent but, except for these small copper sections, several wires are usually stranded together in order to provide flexibility for the larger copper cross sections.

For permanent or fixed installations the conductors (refer Appendix No. 1) are built up in the so-called standard or concentric stranding as follows :—

One centre wire followed by successive layers containing 6, 12, 18, 24, 30 or 36 wires forming strands of 7, 19, 37, 61, 91 or 127 wires.

If the successive layers of wire are all applied in the same direction greater flexibility is obtained but the strand produced is easily crushed or distorted (bird caging), therefore alternate layers of wire are usually applied with right and left-hand lay.

Stranding machines are divided into two main types known as Tubular, or high-speed, machines (as Fig. No. 2) and Cage (Sun and Planet) or low-speed machines (Fig. No. 3).

The Tubular (high-speed) stranding machine is designed for the rapid production of small strands, the largest conductor size

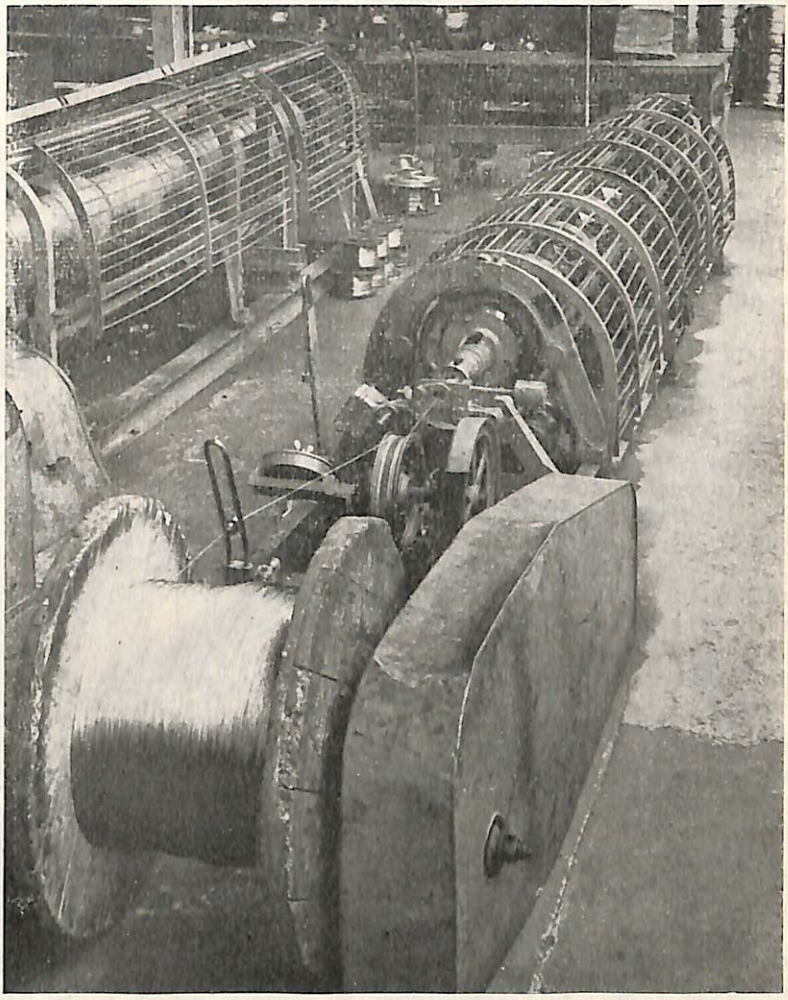


Fig. 2—Tubular (High-Speed) Conductor Stranding Machine.

generally being 7/·064″ (0·0225 sq. in.), but tubular stranders have also been made for producing 19-wire strands. Tubular stranders are operated at speeds greater than 1,000 r.p.m. so dynamic balancing is used to ensure efficient operation.

It will be seen from Fig. No. 2 that the stranding bobbins loaded with copper wire are mounted along the centre line of a steel tube which is cut away at intervals to permit insertion of these bobbins. A copper wire from one bobbin runs through the centre of the tube while the remaining wires are laid along the internal periphery of the tube to the front of the machine, where they pass through a revolving "lay plate." This plate is made of drilled steel bushed with hardened steel dies through which the wires are threaded, after which they pass through a fixed die having an internal diameter corresponding to the external diameter of the stranded conductor. The stranded conductor then passes several times round a "draw off" capstan to ensure a steady take up of the stranded wires, and the rate of drawing off together with the speed of rotation of the carriage controls the "lay" or pitch of the helix formed by each of the wires in the outer layer; then finally the strand is wound on to a cable drum.

Low-speed (Sun and Planet) stranding machines are generally used for conductors containing 19 or more wires and, as shown in Fig. No. 3, the stranding bobbins are located in "floating carriages" pivoted in a large rotating frame. Standard conductors up to 127 wires can be produced in one operation by machines having a number of rotating frames set one behind the other and capable of holding as many as thirty-six bobbins.

1 (2) Flexible Conductors.

When service conditions are such that the finished cable will undergo a considerable amount of flexing, the copper conductors are composed of finer wires which may be bunched and twisted together, or for the larger conductors built up in rope formation from multiple wire strands. (Refer Appendix No. 3).

The stiffness of the conductor has a marked bearing on flexibility, therefore, when this property is of particular importance, careful selection of wire size and length of lay is necessary.

In an I.E.E. Paper, by W. H. Lythgoe,* a review is made of the development of flexible conductors since 1926 (which was the date of the last B.S. specification common to all types of cable) and Table No. 1, extracted from this Paper, shows the various conductor sizes and strands adopted since 1926 for power purposes. This table ignores flexible cords (usually having conductors made up of 0·0076″ or 0·012″ diameter wires) for domestic use and small appliances.

*Lythgoe, W. H., "Standardisation of Power Cables," *Journal Inst. Elec. Engs.*, 1948 Vol. 95, Part II., page 234.

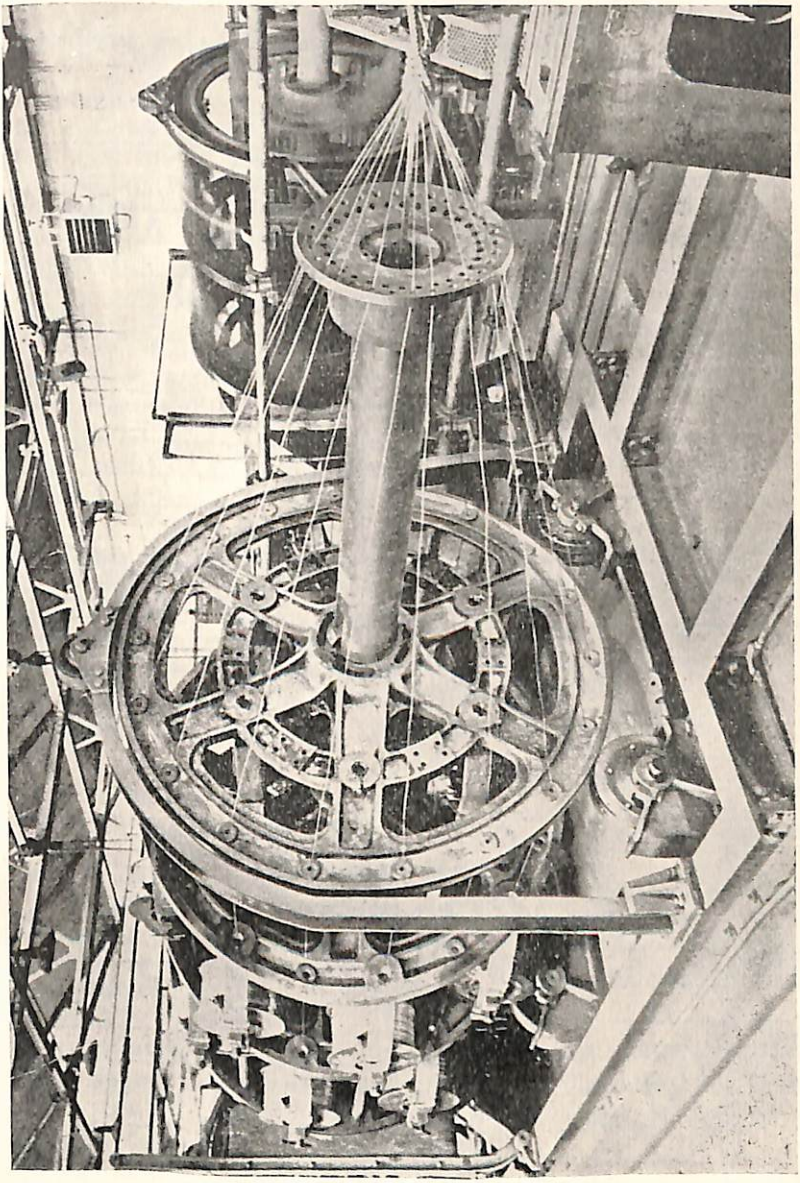


Fig. 3—Cage (Sun and Planet) Low-Speed Conductor Stranding Machine.

TABLE No. 1.

FLEXIBLE CONDUCTORS STANDARDISED SINCE 1926.

Size of Conductor Sq. Inch	Number and Diameter (inch) of Wires					B.S. 7 1926	B.S. 708 1936	B.S. 7 1939 and 1946	B.S. 708 1940	B.S. 1116 1943
	0·0076	0·010	0·012	0·018	0·029					
0·007	162					—	—	—	X	—
0·01		140				X	—	X	X	—
			97			X*	X	X	X	X
0·0145		195				X	—	X	—	—
				60		X*	X	X	X	X
0·0225		296				X	—	X	—	—
			203			—	—	—	X	—
				91		X*	X	X	X	X
0·03			266			X	—	X	X	—
				117		X*	X	X	X	X
0·04			368			X	—	X	—	—
				163		X*	X	X	X	X
0·06			557			X	—	X	—	—
				248		X*	—	X	X	X
0·075			705			X	—	—	—	—
				313		X	—	—	—	—
					121	X*	—	—	—	X
0·10				416		X	—	X	—	—
					160	X*	—	X	—	X
0·12				482		X	—	—	—	—
					186	X*	—	—	—	X
0·15				610		X	—	X	—	—
					235	X*	—	X	—	X
0·20				810		X	—	X	—	—
					312	X*	—	X	—	X
0·25				1017		X	—	—	—	—
					392	X*	—	—	—	X
0·30				1248		—	—	X	—	—
					481	X	—	X	—	X
0·40				1677		—	—	X	—	—
					646	X	—	X	—	X
0·50				2057		—	—	X	—	—
					792	X	—	X	—	X
0·75					1181	—	—	X	—	—
1·0					1645	—	—	X	—	—
Total						28	5	26	10	15

* For trailing cables and similar purposes.

2. RUBBER INSULATED CABLES.

2 (1) The Rubber Mix.

Pure rubber in its natural state is thermoplastic and is unsuitable for the manufacture of rubber insulated cables. Fortunately, however, rubber possesses the property that when mixed with sulphur and other carefully chosen ingredients, and subjected to a controlled period of heat treatment (vulcanisation), it loses its thermoplastic characteristic and becomes elastic within a limited temperature range.

The volumetric percentage of raw rubber used in dielectric compounds is dictated by a number of factors but research and experience show that 50% by volume and upwards is regarded as satisfactory both from the electrical and processing point of view for cables manufactured in this country.

The various materials used in rubber compounding may be split into the following categories, although they tend to overlap to some extent.

Fillers (Mineral Powders).—Fillers are of two main types ; those incorporated to improve the tensile strength and resistance to tearing, flexing, and abrasion (carbon black, zinc oxide, china clay, etc.) and inert fillers which give rigidity or hardness to a compound, resistance to chemical attack, improvement in compounding properties, or which cheapen the product.

Typical inert fillers are Lithopone, talc and whiting.

Accelerators.—Free sulphur in rubber cable dielectrics is detrimental, also the action of sulphur alone for vulcanising is too slow. The present day tendency is to use 0·5 - 1·5% of elemental sulphur calculated on the weight of raw rubber.

The use of an accelerator for hastening the vulcanising process allows the sulphur necessary to be considerably reduced. This practice results in an insulation having improved ageing and resistance to heat, and tends to minimise the tendency for sulphur to corrode the conductor.

Until 1906 the only accelerators used were inorganic oxides, hydroxides, litharge, white lead, quick (slaked) lime, and magnesia.

In 1906, Oenslager discovered that organic amines shortened the time necessary to produce vulcanisation.

Aniline was one of the first used and later thiocarbonilide and para-amino-dimethyl aniline were used.

Modern accelerators are nearly always organic and generally consist of acid derivatives, the fastest (ultra) accelerators being dithro acids or their derivatives.

Accelerators are generally classified according to activity, to the range of temperature at which they give optimum results, or by chemical composition. The activity of many accelerators is improved by the presence in the rubber mix of secondary accelerators such as zinc oxide, litharge or magnesia.

Anti-Oxidants.—Rubber deteriorates in the presence of oxygen and assumes the characteristic appearance known as "perished," but this deterioration can be minimised by including in the mix, prior to vulcanisation, a very small percentage of certain materials which retard the process of deterioration.

The amounts used are quite small—about 1% to 3% of the raw rubber weight.

A good anti-oxidant should be non-toxic, easy to handle in the factory, readily dispersible in a rubber mix, should not retard or accelerate the vulcanising cycle, or have any effect on the colour of the vulcanised product.

The most important materials producing anti-oxidant effects are phenols, aldehyde-amine condensation products, secondary naphthylamine derivatives, ethylene diamine derivatives and ketone-amines.

Wax is of advantage in all insulating compounds and when used in conjunction with suitable anti-oxidants it improves the endurance and moisture resistance characteristics.

Plasticizers or Softeners.—The purpose of a softener is to reduce the amount of work necessary to plasticize the rubber. The addition to a mix of such materials as paraffin wax, pine tar, mineral rubber, palm oil, etc., in appropriate proportions acts, in effect, as an internal lubricant and thereby facilitates the mixing of the raw rubber and other constituents.

Under this heading can be included organic material known as "factice," "vulcanised oil," or "rubber substitute." Factices are soft materials which have a superficial resemblance to rubber. Bituminised factice has been used extensively in cables used in wet and exposed positions such as railway signalling cables.

Colouring Agents (Pigment).—In order to obtain white dielectrics, ingredients such as lithopone, zinc oxide, titanium dioxide and

zinc sulphide are used, while pigments such as ferric oxide, ultramarine blue and zinc chromate produce red, blue and yellow rubbers.

For insulation purposes it is important that all ingredients added to the clean rubber are free from water soluble salts, manganese, copper and iron and they should be of fine particle size.

2 (2) Physical Properties of the Insulation.

Early rubber insulated wiring cable standards were based on three qualities, 2,500 megohm, 600 megohm and Nonazo grades all using the traditional "pure and V.I.R. insulation."

An inner layer of pure unvulcanised rubber was intended to provide the necessary electrical properties, and it was followed by a white or drab coloured non-vulcanising layer known as the "separator" and finally an outer layer of vulcanizable rubber.

The separator (or middle layer) was intended to keep the sulphur in the vulcanised rubber from the inner coating of pure rubber, but experience proved that the sulphur will migrate from the outer layer to the separator so, subsequently, the inner layer was made a vulcanizing compound similar to the outer layer and the "pure and V.I.R." insulation used for over two decades came into being.

Later, service experience also revealed that the inner layer of pure rubber is not satisfactory for tropical conditions and this "pure" unvulcanized layer was then replaced by a layer of vulcanised rubber.

Thus, the standard insulation became a vulcanised rubber compound applied in three layers (although Clause No. 16 of B.S. 7—1946 permits the use of two layers or an extruded dielectric) also the classification by megohms was dropped in favour of a voltage classification.

The physical properties required from the insulation are such that the cable will withstand the normal hazards of installation and give trouble-free service through the long life anticipated for rubber insulated cables.

Assessment of the "quality" of rubber compounds is usually done on the basis of tests for tensile strength, elongation at break, rigidity and set, these tests being carried out in the "as received" condition and after accelerated ageing.

The tensile strength is measured by taking a cable sample, removing the conductor and outer coverings so as to leave the dielectric in the form of a tube. Marks are then made on the sample, say 1″ or 2″ apart, and this sample is secured in the jaws of a tensile testing machine and stretched at a pre-determined rate

until rupture occurs. From the load at break and the original cross-section of the sample the tensile strength in lb./sq. in. is computed.

Elongation is obtained by subtracting the original distance apart of the marks from their final distance apart, and expressing this as a percentage of the original distance. The rigidity, or modulus, of the rubber is determined by measuring the load at some elongation before the breaking point is reached, the ratio of the two being the value of rigidity.

Because of the disposition to ageing of rubber in service, considerable attention has been given to devising an accelerated life test by which the behaviour of test samples of rubber over considerable periods of service may be predicted, the object of the tests being to reproduce in samples during a period of several hours, the effects of many years of natural ageing.

The ageing effect produced must be not only one of degree but also of character, as the same type of deterioration must result with the formation of the same chemical products.

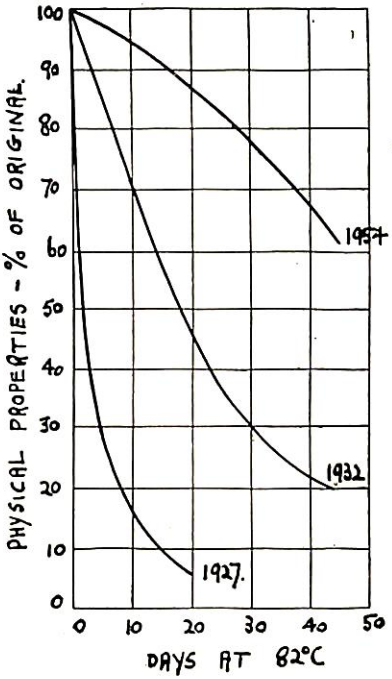
Oxygen in the atmosphere is the primary cause of deterioration of rubber dielectrics, and experience has revealed that the ageing properties of rubber compounds could be determined by measuring the extent to which they retain their initial properties after periods of accelerated ageing treatment.

Many forms of accelerated ageing tests based on heating samples have been proposed and one such test, devised by Dr. Geer over thirty years ago, has been widely used. When applied to rubber cables, samples of the dielectric, from which the copper conductor has been withdrawn and the outer coverings removed, are stored in a dark oven and maintained at an elevated temperature in a constant stream of air provided by a fan. The temperature adopted for the Geer oven test is such as to produce relatively quick deterioration of the samples, but not so high as to produce secondary effects—the temperature specified in B.S. 7 is 82·2 $\pm$ 0·5°C. for 120 hours.

The test recommended by Geer was followed eight years later by another important accelerated ageing test proposed by Birer and Davies in America—the oxygen bomb test. In this test the normal effect of oxidation is accelerated by subjecting the sample to pure oxygen gas at a pressure of 300 lb. p.s.i. in a steel autoclave, the temperature used being 70°C. or 80°C.

The basis of both tests is to subject the samples to the specified heat treatment for a given period of time, after which physical measurements are made and the percentage depreciation is calculated.

Relative Ageing Properties of Dielectric Mixes on Basis of Accelerated Ageing Tests.



Increased Resistance to Oxidation built into VR Compounds at various stages of development.

Fig. 4.

Ageing tests are, of course, arbitrary until correlated with the results of natural ageing, and this data has been obtained by submitting samples to laboratory tests while duplicate samples were sent to India for natural storage and return to this country at appropriate intervals.

Fig. No. 4, due to B. B. Evans,* shows the resistance to accelerated ageing of the types of V.I.R. Mix used in 1927, the early 1930s and at the present post-war period and illustrates very clearly the progressive improvements in ageing properties in rubber cable compounds over the past twenty years.

B.S. 7, 1946, referred only to cable dimensions and general construction, but the latest issue (1953) now includes quality clauses.

The physical requirements for V.R. insulants to B.S. 7, 1953, are summarised as follows :—

TABLE No. 2.

PHYSICAL REQUIREMENTS FOR V.R. INSULATION.

	Less than 0·030 Radial Thickness of Insulation	Cables with Conductor Diameter 0·32 Inch or Greater	All Other Sizes
Tension strength lb./sq. in. maximum	1,800	1,600	2,000
Elongation at break per cent. minimum, ...	360	320	400
After accelerated ageing : Change in tension strength (per cent. maximum), ...	25	25	25
Change in elongation at break (per cent. maximum)	15	15	15
Tension set (per cent maximum)	30	30	30

2 (3) Electrical Properties of the Insulation.

The electrical properties required for a rubber insulation are high breakdown strength and insulation resistance. The breakdown strength of rubber insulation under normal conditions (and

*Evans, B. B., "Developments in Rubber Cables," *New Zealand Electrical Journal*, May 25th, 1949.

in the absence of deterioration through ageing and of local defects such as accidental foreign inclusions, mechanical damage, etc.) are usually far beyond service requirements, so that for the lower voltage range of V.R. cables mechanical considerations limit the radial thickness of insulation used.

Typical short time breakdown voltages on samples of 250 volt cables vary from 10 kV to 20 kV. depending on the dielectric wall thickness, and for 660 volt cables breakdown values from 18 kV. to over 30 kV, have resulted with varying wall thicknesses of insulation.

The late W. Bowen in an I.E.E. Paper examined the thickness of insulation required for various grades of 250 volt rubber, P.V.C. and Polythene dielectrics which were tested at 1,500 volts A.C. 50 c/s.

Since no breakdown must occur at this test voltage he assumed 2,000 volt A.C. (corresponding approximately to 3,000 volt D.C.) as the level at which breakdown may occur. The effect of this assumed minimum breakdown voltage on different dielectric materials will result in exceedingly thin dielectric walls as shown in Table No. 3 below if electrical requirements were the only criterion.

TABLE No. 3.*

Material	Approximate Electric Strength Volts/mil	Minimum Wall Thickness of Insulation on 250 V. Grade Cables Mils†
Good Quality Vulcanised Rubber (B.S. 7, Specification)	500	6
Poor Quality Rubber ... ... (Amendment No. 1, B.S. 7)	350	8·5
P.V.C. Dielectric Grade ... (Appendix B.S. 7, Specification)	400	7·5
P.V.C. Sheathing Grade ...	350	8·5
Polythene	1,000	3

Table No. 4 shows comparative minimum average wall thicknesses of dielectric given in B.S. 7, 1946 and 1953.

(* Refer I.E.E. Paper by W. Bowen : "Factors Governing Specifications for Electric Power Cables," *Journal I.E.E.*, Volume 95, Part 2, Page 551).

† 1 Mil = 1/1,000th inch.

TABLE No. 4.

B.S. No. 7, SPECIFICATION.

COMPARATIVE RADIAL THICKNESSES OF V.R. INSULATION.

Cross Sectional Area of Conductor	No. and Diameter of Wires	Insulation Thickness (Average)			
		250 Volt W.P.		660 Volt W.P.	
		B.S. 7, 1946	Revised B.S. 7, 1953	B.S. 7, 1946	Revised B.S. 7, 1953
Sq. Inch	Inch	Inch	Inch	Inch	Inch
0·0015	1/044	0·034	0·030	0·055	0·055
0·002	3/029	0·036	0·030	0·056	0·055
0·003	3/036	0·038	0·030	0·057	0·055
0·003	1/064	0·036	0·030	0·057	0·055
0·0045	7/029	0·039	0·030	0·058	0·055
0·007	7/036	0·041	0·035	0·059	0·060
0·01	7/044	0·043	0·035	0·060	0·060
0·0145	7/052	0·046	0·040	0·061	0·060
0·0225	7/064	0·049	0·040	0·062	0·060
0·03	19/044	0·052	0·045	0·062	0·060
0·04	19/052	0·056	0·052	0·063	0·065
0·06	19/064	0·062	0·055	0·065	0·065
0·10	19/083	—	—	0·072	0·070
0·15	37/·072	—	—	0·080	0·080
0·20	37/·083	—	—	0·088	0·090
0·30	37/·103	—	—	0·102	0·100
0·40	61/·093	—	—	0·114	0·110
0·50	61/·103	—	—	0·121	0·120
0·75	91/·103	—	—	0·131	0·130
1·00	127/·103	—	—	0·141	0·140

Table No. 4 gives the range of conductor sizes and insulation thicknesses for V.R. 250 and 660 volt cables to B.S. 7, 1946, and the revised (1953) edition of that specification; the insulation thicknesses specified in B.S. 7, 1946, were approximately the same as those specified for low voltage cables in 1904.

It is interesting to note that foreign specifications do not provide for a wide range of cables below 660 volt working pressure; presumably it is considered that the mechanical requirements are such that the resultant dielectric wall is adequate for operation at 660 volts or even lower.

In America a number of rubber compounds are used for varying service conditions and Table No. 5 provides a review of American rubber compounds used for general purpose electrical wiring.

TABLE No. 5.

AMERICAN RUBBER AND THERMOPLASTIC COMPOUNDS FOR GENERAL PURPOSE WIRING.

NATIONAL ELECTRICAL CODE TYPES: INSULATION, TEMPERATURE RATING AND USE OF VARIOUS WIRES AND CABLES FOR USE IN BUILDINGS.

Trade Name	Type Letter*	Max. Operating Temp.	Insulation	Outer Cover	Special Provisions and Use
Rubber Covered Fixture Wire ...	RF-1	60° C. 140° F.	Code Rubber	Cotton	Fixture wiring limited to 300 volts.
Solid or Stranded	RF-2	60° C. 140° F.	Code Rubber	Cotton	Fixture wiring and as permitted in 3103 N.E.C.
Rubber Covered Fixture Wire ...	FF-1	60° C. 140° F.	Code Rubber	Cotton	Fixture wiring limited to 300 volts.
Flexible Strand	FF-2	60° C. 140° F.			Fixture wiring.
Heat Resistant, Rubber Covered	RFH-1	75° C. 167° F.	Heat Resistant Rubber	Cotton	Fixture wiring limited to 300 volts.
Fixture Wire, Solid or Stranded	RFH-2	75° C. 167° F.	Heat Resistant Rubber	Cotton	Fixture wiring and as permitted in 3103 N.E.C.
Heat Resistant, Rubber Covered	FFH-1	75° C. 167° F.	Heat Resistant Rubber	Cotton	Fixture wiring limited to 300 volts.
Fixture Wire, Flexible Stranded	FFH-2	75° C. 167° F.	Heat Resistant Rubber	Cotton	Fixture wiring and as permitted in 3103 N.E.C.
Latex Rubber, Fixture Wire ...	RUF	60° C. 140° F.	90% Unmilled Grainless Rubber	Cotton	Fixture wiring and as permitted in Sec. 3103 N.E.C.
Solid or Stranded Flexible Strand	RUFF	60° C. 140° F.	90% Unmilled Grainless Rubber	Cotton	Fixture wiring.
Thermoplastic Covered, Fixture Wire, Solid or Stranded	TF	60° C. 140° F.	Thermoplastic	None	Fixture wiring and as permitted in Section 3103 N.E.C.
Thermoplastic Covered, Fixture Wire Flexible Stranding	TFF	60° C. 140° F.	Thermoplastic	None	Fixture wiring.
Code Rubber	R	60° C. 140° F.	Code Rubber	Moisture resistant, flame retardant fibrous covering	General use.
Heat Resistant	RH	75° C. 167° F.	Heat Resistant Rubber	Moisture resistant, flame retardant fibrous covering	General use.

TABLE No. 5 (continued).

AMERICAN RUBBER AND THERMOPLASTIC COMPOUNDS FOR GENERAL PURPOSE WIRING.

NATIONAL ELECTRICAL CODE TYPES: INSULATION, TEMPERATURE RATING AND USE OF VARIOUS WIRES AND CABLES FOR USE IN BUILDINGS.

Trade Name	Type Letter*	Max. Operating Temp.	Insulation	Outer Cover	Special Provisions and Use
Moisture Resistant Rubber ...	RW	60° C. 140° F.	Moisture Resistant	Moisture resistant, flame retardant	General use in wet locations.
†Heat Moisture Resistant ... Latex Rubber	RHW RU	75° C. 60° C. 140° F.	Heat Moisture Resistant ... 90% Unmilled Grainless Rubber	Fibrous covering ... ... Moisture resistant, flame retardant fibrous covering	General use—600 volts.
Thermoplastic	T	60° C. 140° F.	Flame Retardant Thermoplastic	None	General use—600 volts.
Moisture Resistant Thermoplastic	TW	60° C. 140° F.	Flame Retardant, Moisture Resisting Thermoplastic	None	General use in wet locations 600 volts.
Thermoplastic Asbestos	TA	90° C. 194° F.	Thermoplastic and Asbestos ...	Flame retardant, cotton braid ...	Switchboard wiring only.
Armoured Cable	AC AV	*See Note*	Rubber Varnished Cloth ...	Interlocked galvanised steel ...	N.E.C. Art. 334.
Nonmetallic Sheathed Cable, ...	NM NMC	*Note*	Rubber or Thermoplastic ...	Moisture and flame resistant fibrous Neoprene or thermoplastic	Dry locations, 600 volts, N.E.C. Art. 336. Wet locations, 600 volts, N.E.C. Art. 336.
Service Entrance	SE ASE USE	*Note*		Moisture and flame resistant fibrous or Neoprene metallic armoured as approved	Concentric type limited to 150 volts to ground Interior wiring to ranges and water heaters only.

Note.—Depends upon type of insulation used. N.E.C.—National Electrical Code.

* Type letters are amplified by following suffixes where required.

D—2 cond. duplex or flat twin.
M—Multiple conductor—3 or more.
L—Lead covered.

10—for use at not more than 1,000 volts
20—for use at not more than 2,000 volts
30—for use at not more than 3,000 volts
40—for use at not more than 4,000 volts
50—for use at not more than 5,000 volts
Type letter alone indicates 600 volts

† Introduced 1954.

A.S.T.M. (American Standards for Testing Materials) have recently included an 80° C. ozone resisting insulation (Butyl Rubber). The use of this material as an all-purpose insulation would greatly simplify the present rather complicated standards summarised above.

V.R. insulated cables for high voltage service to B.S. 7, 1953, specification have the following average radial thicknesses of insulation :—

TABLE No. 6.

THICKNESSES OF V.R. INSULATION FOR HIGH VOLTAGE CABLES.

CENTRE-POINT-EARTHED SYSTEM.

Nominal Cross Sectional Area (Sq. Inch)	Conductor Size (No. and Diameter of Wires)	3,300 Volt	6,600 Volt	11,000 Volt
0·0225	7/·064	0·12	0·20	0·30
0·20	37/·083	0·12	0·20	0·30

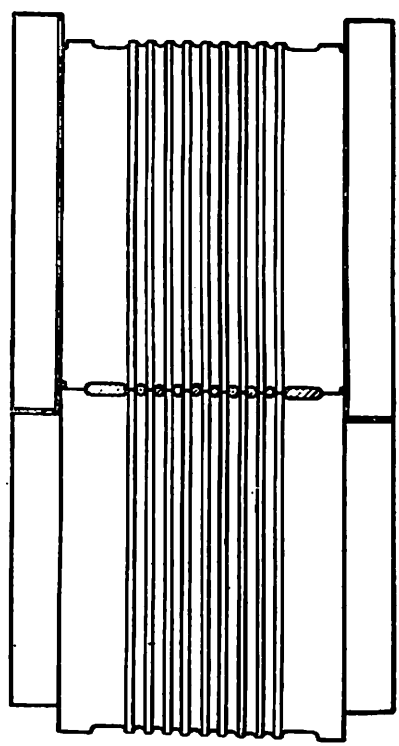


Fig. 5—Longitudinal Cutting Rolls.

3. APPLICATION OF THE RUBBER INSULATION TO THE CONDUCTOR(S).

Various alternative methods are used for applying the rubber layer around the conductors and these techniques are described briefly below :—

3 (1) The Longitudinal Method.

With this process, two or three successive strips of rubber compound are placed above and below the conductors, pressed together and cut by means of accurately grooved rollers, thus forming concentric layers of insulation. (Refer Fig. No. 5). The pressure is exerted whilst the rubber is in an unvulcanised state and a separate subsequent heat treatment (vulcanising) causes the layers of rubber and the seams to unite intimately and produce an homogeneous dielectric. The longitudinal technique ensures that 24-36 copper conductors can be insulated at one time (refer Fig. No. 6).

Efficient production is dependent on the condition and thickness of the rubber strip and the correct cutting edge on the longitudinal rolls.

3 (2) Lapping Method.

For stranded conductors larger than 0·0225 sq. in. (7/·064) it is common practice to apply the rubber insulating tapes on lapping machines which are fitted with a number of heads provided with revolving spindles on which the rolls of rubber tape are positioned. As the stranded conductor passes through the lapping machine, the revolving heads lap the rubber tapes spirally around the conductor with alternate right and left-hand lay. Unless care is exercised air may be trapped between the layers of rubber and therefore it is applied with a slight tension.

3 (3) Continuous Vulcanisation (C.V.) Process.

In Great Britain at the present time, the bulk of the insulating of V.R. cables is by the longitudinal process described above, but there is a body of opinion that the production efficiency with this technique is low when compared with "C.V." technique. The C.V. process has been generally used for some years now in many continental and American factories and increasing use is also being made of this method of production in this country, because of the economies which result.

The C.V. machine consists essentially of an extruder for applying the rubber to the wire and a tube which contains steam at high pressure in which the rubber is vulcanised (Fig. No. 7).

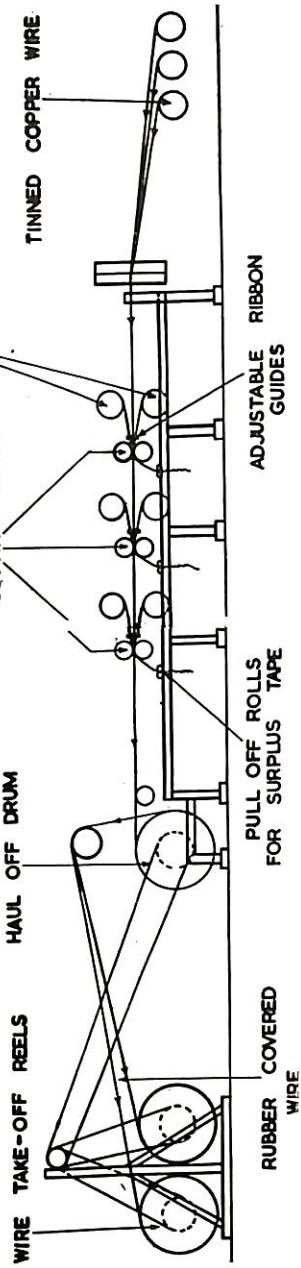


Fig. 6—Longitudinal Covering Machine.

Vulcanisation is carried out in 10-30 seconds at 200-225 lbs. p.s.i. steam pressure and, consequently, vulcanising tubes 150 ft.-200 ft. long are used. The cable is passed into the steam whilst the rubber insulation is in the unvulcanised condition, the vulcanised rubber cable then passing out of the steam into the atmosphere.

Cable is produced on such C.V. machines at linear speeds varying between 50 and 900 ft. per minute. This means that vulcanising times will vary between three minutes and 10 seconds when using a tube 150 ft. long. Such vulcanising times are much shorter than those used in the traditional discontinuous processes where times varying between 20 and 45 minutes are usual. The very short vulcanising times associated with the C.V. process are made possible by the use of steam pressure approximating to 200 lbs. p.s.i. and also by modified rubber mixes.

The requirements for an efficient production by the C.V. process have been summarised by Harrison* as follows :—

(*a*) Conductors free from lumps, welds and defects.

(*b*) Controlled plasticity of the compounds.

(*c*) Controlled temperature at extruder feed.

(*d*) Precision head with self-centering core and dies and accurate temperature control.

(*e*) Continuous feed, efficient worm and extrusion direct on the wire without excess rubber in the head.

(*f*) Cooling of the cable under pressure after passing through the vulcaniser tube.

(*g*) Vertical extrusion and vulcanising tube for cables over 0·5 inch diameter to eliminate sagging.

3 (4) The Latex Insulating Process.

Rubber Latex consists of particles of rubber dispersed in water and is, therefore, an emulsion.

In theory, therefore, it follows that a wire could be passed through a liquid and the water dried off, thereby leaving a film of rubber on the wire and this process could be repeated in order to build up any desired thickness of insulation.

Fig. No. 8 shows a schematic drawing of the equipment used for insulating wires by the latex dip process. Dykes† has

* "The Fundamentals of Rubber Technology," Lecture 6, by H. C. Harrison. Publication issued by Imperial Chemical Industries, Ltd. (Dyestuffs Division).

† Dykes, J. B., "The Latex Process of Wire Covering." *Distribution of Electricity*, No. 200, Vol. XXVI, September, 1953.

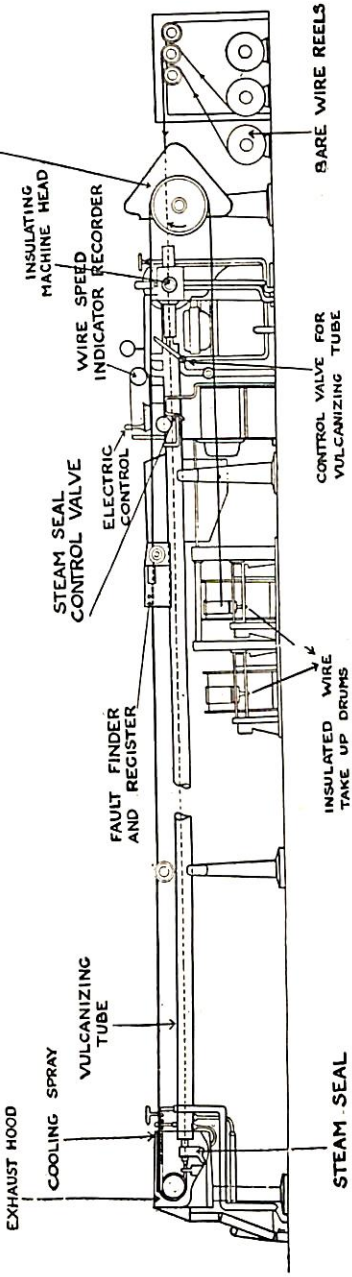


Fig. 7—Continuous Insulating and Vulcanising Machine.

summarised some of the important factors influencing the covering operation as follows :—

(*a*) Viscosity of the compounded latex.

(*b*) Size of the conductor.

(*c*) Speed of covering.

These features are independent. For a given size of conductor, variation of the viscosity of the compounded latex will give a variation in the thickness of the applied latex film. For a definite viscosity of the compounded latex the speed of application will affect the thickness of the layer picked up, and the number of dips in the latex compound will obviously regulate the final thickness of insulation. From these considerations it will be appreciated that as the covering of a conductor proceeds, using the same latex compound for all dips, the layer of film applied in each dip will vary. The variation between two layers applied can be

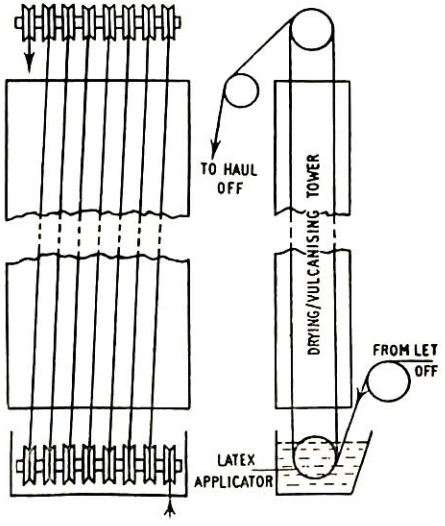


Fig. 8—Diagrammatic Representation of the Plant for Continuous Latex Covering.

of the order of 0·0015″ and provision must be made for this in the drying operation. The speed of operation is limited by the drying capacity of the plant, as it is essential to ensure that each individual layer is properly dried out before applying a further layer.

The resultant latex insulant has the physical properties associated with compounds consisting of almost pure rubber. Elongations at break of 800% are readily obtained, associated with low values of sub-permanent set, implying a very soft and flexible insulation.

Latex insulation is characterised by low permittivity, 2·8, and high dielectric resistance. The dielectric resistance of 16 mils of latex insulation on a 0·032″ conductor is of the order of 25,000 megohms per thousand yards.

The following information relating to American latex insulated wires is of interest.

TABLE No. 7.

INSULATION THICKNESS, TEST VOLTAGE, AND INSULATION RESISTANCE FOR SIGNAL CABLE TO BE OPERATED UP TO 600 VOLTS PER I.M.S.A. SPECIFICATION No. 16, 1951.

A.W.G.	Insulation Thickness (Inches)	Test Voltage	Insulation Resistance at 60° F. Megohms (Minimum)
19	·015	1,500	10,000
18	·015	1,500	10,000
17	·015	1,500	10,000
16	·015	1,500	10,000
15	·018	1,800	10,000
14	·018	1,800	9,300
13	·018	1,800	8,650
12	·018	1,800	8,050
11	·018	1,800	7,500
10	·018	1,800	7,000

Percentage power factor values are 0·8 and the dielectric strength (rising breakdown, volts per mil) 800.

I.M.S.A. Specification 16 (1951) also calls for the following test values :—

Dielectric constant (S.I.C.),

After 24 hours immersion	...	2·9 maximum
% change 1—14 days, ...	...	10% maximum
% change 7—14 days, ...	...	3% maximum

4. APPLICATION OF PROOFED TAPE OVER THE INSULATED CONDUCTOR.

Since the life of the V.R. dielectric is affected by the deteriorating influence of oxygen, the nature of the material applied over the dielectric may have an important effect on the service life of the cable.

The first wrapping generally applied over the rubber insulation is a proofed tape (V.R. insulated cores for tough rubber sheathed cables to B.S. 7 Specification are, however, untaped), applied before the vulcanising process.

This proofed tape is an expensive component of the cable, and with modern manufacturing techniques there is to-day a strong body of technical opinion that the proofed tape could be safely dispensed with.

For the taping operation the insulated conductor passes through a hollow vertical slotted tube at the base of which is a plate to hold the roll of tape, the end of which passes round a tension spindle and then on to the core.

The spindle and plate revolve, applying the tape at a predetermined angle around the core with the proofed surface on the outside—saving in tape is achieved by selecting the correct lay, overlap and width of tape.

For certain applications where the proofed tape is applied for retaining the shape of the insulated core during the vulcanising process, it can be used several times with the aid of a detaping machine ; the technique used being a reversal of the normal taping operation and as the tape is unwrapped, it is wound on a driven spindle.

Vulcanising Process.—For this operation the insulated cores are either wound evenly on cylinders or coiled in shallow metal trays containing french chalk and then vulcanised (or cured) in steam heated chambers—refer Fig. No. 9.

With cables over $\frac{1}{2}$" diameter it is normal practice to cure the core wrapped in tapes, otherwise the weight of the conductor may cause decentralisation.

The pressure or temperature of steam in the vulcanising chamber and the length of time of curing depend upon each other and upon the quality and thickness of the rubber.

In certain cases cables may be encased in a lead jacket and vulcanised on a drum, the lead afterwards being stripped off and used again.

The use of fatty acids and carbonates should be avoided to prevent the formation of gas between the lead and rubber sheathing during vulcanisation.

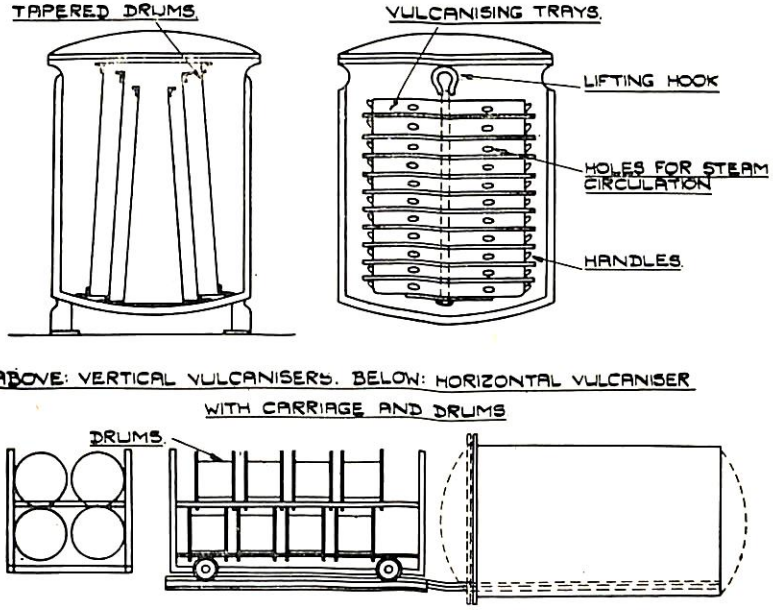

TAPERED DRUMS.
VULCANISING TRAYS.
LIFTING HOOK
HOLES FOR STEAM CIRCULATION
HANDLES.
ABOVE: VERTICAL VULCANISERS. BELOW: HORIZONTAL VULCANISER WITH CARRIAGE AND DRUMS
DRUMS.

Fig. 9

5. PROTECTIVE COVERINGS.

Various standard methods are adopted for protecting the rubber insulated conductors and these are reviewed below :—

5 (1) Taped, Braided and Compounded Finish (T.B. and C.).

Over the taped core is applied a close cotton braid* (the cotton threads of the braid being twisted as in a maypole) which is subsequently impregnated with a water and weather proof compound of a distinctive colour.

For multicore braided cables the cores are either laid parallel (*e.g.*, flat twin types) or twisted together with the interstices between the cores filled with a suitable worming material, then taped, braided and compounded overall.

In the case of the large diameter cables, a jute braid may be used in place of a cotton braid. If flexibility is required, flexible cords with a glace cotton, artificial silk, braided and lacquered or braided and compounded (Workshop) finish are used, dependant on the purpose for which they are required.

5 (2) Tough Rubber Sheathed (often referred to as Cab Tyre Sheath).

This type of protection was originally designed for use with flexible cables subject to rough usage and the possibility of mechanical damage, but it is now also widely used as a sheathing for house wiring cables, portable trailing cables and mining cables. Such a sheathing is still subject to the principle of oxidation mentioned in connection with the dielectric and also it must be compounded so as to possess the requisite toughness, resilience and abrasion resistance. These properties are particularly important in cables intended for work in mines and quarries and for use with underground coal cutters, electric drills, conveyors, loaders, etc.

For sheathing compounds ingredients are added to the mix for reinforcing purposes and detailed research and testing has revealed that the reinforcing action imported by a compounding ingredient is related among other things to its particle shape and size, the smaller the filler the better its reinforcing action, and the best reinforcing ingredients at present commercially available are the carbon blacks.

In order to obtain the requisite degree of toughness, the sheathing mix has to be loaded with materials which do not provide good insulating properties. Consequently, when the tough rubber sheath is applied over standard V.R. insulated conductors, the moderate insulating property of the T.R.S. is disregarded in the evaluation of the insulation properties of these cables. The wall thickness of T.R.S. for standard V.R. cables to B.S. 7 Specification is given in the following table.

* "Braids and Braiding Machines," W. Douglass, *Distribution of Electricity*, No. 213, Vol. XXVIII, November, 1955, p. 222.

TABLE No. 8.

AVERAGE RADIAL THICKNESS OF TOUGH RUBBER SHEATH TO B.S. No. 7, 1953, SPECIFICATION.

Average Thickness of Tough Rubber Sheath	Calculated Diameter Under T.R.S. (Single and Multicore Cables)
Non-Flexible Cables and Flexible Cords	
Inch	Inch
0·040	up to 0·250
0·050	0·251 ... ... 0·500
0·060	0·501 ... ... 0·750
0·075	0·751 ... ... 1·000
0·100	1·001 ... ... 1·250
0·120	1·251 ... ... 1·500
0·140	1·501 ... ... 1·750
0·160	1·751 ... ... 2·000
0·190	2·001 ... ... 2·250
0·220	2·251 ... ... 2·500
0·250	2·501 ... ... 2·750
0·250	2·751 ... ... 3·000
Flexible Cables	
0·100	up to 0·600
0·125	0·601 ... ... 1·120
0·150	1·121 ... ... 1·750
0·175	1·751 ... ... 2·000
0·200	2·001 ... ... 2·250
0·225	2·251 ... ... 2·500
0·250	2·501 ... ... 3·000

Above table has been used to determine the average thickness of T.R.S. on cables complying with B.S. No. 7 Specification—it is also applicable to miscellaneous tough rubber sheathed cables not included in B.S. No. 7 Specification.

5 (3) Lead Alloy Sheathing.

The rubber insulated cores are covered with a lead alloy sheath (usually Alloy E containing 99·4/0·4/0·2% lead/tin/antimony respectively).

This type of cable is used for fixed installations inside or outside buildings in lieu of T.B. and C. cable in conduit.

Some L.A.S. cables have immediately under the metal sheath a wire as an earth continuity conductor. This conductor, which will be in contact with the metal sheath throughout its length, can be used to bridge over joints and to connect to individual pieces

of apparatus in order to ensure earthing of the frame or other metal cables. The following table gives a summary of lead wall thickness used for the normal range of cable diameters to B.S. 7, 1953, Specification.

TABLE No. 9.

AVERAGE RADIAL THICKNESS OF LEAD ALLOY SHEATH TO B.S. No. 7, 1953, SPECIFICATION.

Average Thickness of Lead Alloy Sheath	Calculated Diameter Under Lead Sheath (Single and Multicore Cables)
Inch	Inch
0·040	up to 0·250
0·050	0·251 ... ... 0·500
0·060	0·501 ... ... 0·750
0·075	0·751 ... ... 1·000
0·090	1·001 ... ... 1·250
0·100	1·251 ... ... 1·500
0·110	1·501 ... ... 1·750
0·120	1·751 ... ... 2·000
0·120	2·001 ... ... 2·250
0·130	2·251 ... ... 2·500
0·130	2·501 ... ... 2·750
0·140	2·751 ... ... 3·000
0·140	3·001 ... ... 3·251

Notes.

(1) Above table has been used to determine the average thickness of lead alloy sheath on cables complying with B.S. 7 specification—it is also applicable to miscellaneous lead sheathed cables not included in above specification.

(2) The thickness of sheath for flat cables should be the same as that for a circular cable having a corresponding conductor size and number of cores, but omitting the tape on the cores and the tape over the laid up cores where these are used in circular cables. The thickness of lead alloy sheath for cable having an earth continuity conductor should be the same as that for the corresponding cable without an earth continuity conductor.

5 (4) Steel Armouring.

If the conditions of installation necessitate mechanical protection multicore cables (with or without a lead sheath) are armoured by means of a layer of galvanised steel wires applied in a tight helix over a bedding of fibrous material.

This type of finish is either applied "SERVED", *i.e.*, with an outer covering of hessian tapes, jute strings or a close braid, or "BRIGHT", *i.e.*, without any additional fibrous covering over the armouring.

The further protection afforded by a ring of steel wires is also necessary where the cable is liable to mechanical impact or is subject to strain.

For installation inside buildings, the cables may be left "BRIGHT", but when installed outside they should be protected against corrosion by a compounded serving.

5 (5) Aluminium Sheathing.*

Apart from its use as a sheathing material for paper insulated power cables, considerable use is also being made to-day of V.R. insulated and aluminium sheathed cables for the wiring of factories and buildings.

The following Table provides a summary of the radial thickness of aluminium sheath used on cables manufactured to the requirements of B.S. 7 Specification.

TABLE No. 10.

RADIAL THICKNESS OF ALUMINIUM SHEATH TO B.S. 7, 1953, SPECIFICATION.

Diameter Under Aluminium Sheath		Thickness of Aluminium Sheath
From	To	
Inch	Inch	Inch
—	0·380	0·036
0·381	0·489	0·041
0·490	0·597	0·046
0·598	0·706	0·051
0·707	0·869	0·056
0·870	1·086	0·068
1·087	1·304	0·078
1·305	1·521	0·088
1·522	1·739	0·098
1·740	1·956	0·110
1·957	2·173	0·120
2·174	2·391	0·130
2·392	2·608	0·140
2·609	2·826	0·150

Notes.

(1) Above aluminium sheath thicknesses are based on the die-ing down technique of applying an aluminium sheath around the insulated conductor(s).

(2) The aluminium sheath shall contain not less than 99·5% aluminium, the maximum limits for impurities being those for Material TIB of B.S. 1471, viz. :—

Copper	not	more	than	0·05	per cent.
Silicon	,,	,,	,,	0·3	,, ,,
Iron	,,	,,	,,	0·4	,, ,,
Manganese	,,	,,	,,	0·05	,, ,,

*"Aluminium in Electrical Engineering," Bailey, J. C., *Metallurgia*, Vol. 51, No. 304, February, 1955, p. 81.

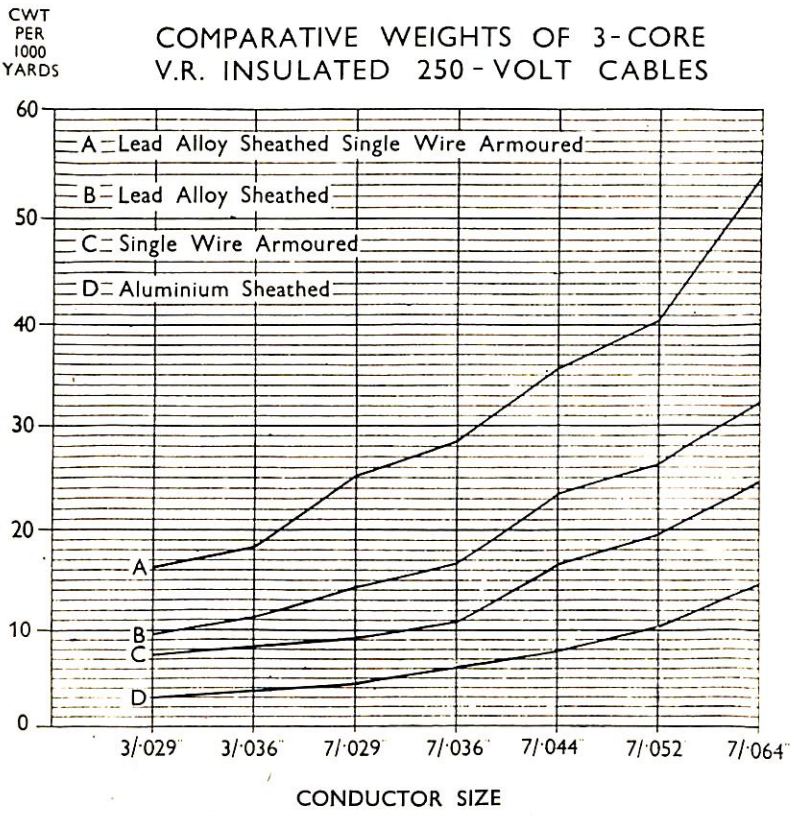

CWT PER 1000 YARDS
COMPARATIVE WEIGHTS OF 3-CORE V.R. INSULATED 250-VOLT CABLES
A = Lead Alloy Sheathed Single Wire Armoured
B = Lead Alloy Sheathed
C = Single Wire Armoured
D = Aluminium Sheathed
60
50
40
30
20
10
0
A
B
C
D
3/·029"
3/·036"
7/·029"
7/·036"
7/·044"
7/·052"
7/·064"
CONDUCTOR SIZE

Fig. 10.

Aluminium sheathed cables are considerably lighter than equivalent cables having other forms of metallic protection and a typical comparison of weights is shown in Fig. No. 10. They are also more robust than lead alloy sheathed cables, allowing steel armouring to be dispensed with in many cases.

Lightness and reduced tendency to sag permit aluminium sheathed cables to be supported at wide intervals, while resistance to fatigue avoids the need for special precautions when they are installed in positions subject to severe vibration.

In view of their greater rigidity aluminium sheathed cables require a larger force to bend than lead alloy sheathed cables and a bending tool may be necessary for large diameters.

Minimum bending radii recommended for these cables with rubber insulation are as follows :—

Diameter Over Sheath	*Minimum Bending Radii (Inside Bend).*
Up to $\frac{1}{2}$ inch	8 × Sheath Diameter
Above $\frac{1}{2}$ inch up to $\frac{3}{4}$ inch, ...	10 × Sheath Diameter
Above $\frac{3}{4}$ inch up to $1\frac{1}{4}$ inch, ...	12 × Sheath Diameter
Above $1\frac{1}{4}$ inch, ...	15 × Sheath Diameter

6. ORDERING SPECIFICATION.

The following are the important details to be specified when ordering V.R. cables :—

(1) Size of conductors (or current rating) and the number of cores required.

(2) Type of finish such as taped, braided and compounded, T.R.S., armoured, etc.

(3) System voltage and details of supply system on which the cables will be used.

(4) The colour of core insulation required.

Standard V.R. cables are normally packed in cartons or on reels of 50 yards or 100 yards lengths.

Tests.

The main tests specified in B.S. 7 are :—

Tinning Test.—To determine the efficacy of the tin coating on wire.

Voltage Test.—A test with alternating voltage of 50 cycles per second, maintained for 15 minutes between the conductor and the water in which the cable is immersed, the voltage being in accordance with the following tables :—

TABLE No. 11.

VOLTAGE TESTS ON V.R. CABLES.

Service Voltage	A.C. Test Voltage Applied for 15 Minutes	
	At Works	After Installation
250-Volt Cables and Flexible Cables	1,500	500
*660-Volt Cables and Flexible Cables	3,000	1,000
†3,300-Volt Cables	10,000	6,000
†6,600-Volt Cables	18,000	12,000
†11,000-Volt Cables	25,000	20,000

TABLE No. 12.

VOLTAGE TESTS ON FLEXIBLE CORDS.

Type of Flexible Cords	A.C. Voltage	Conditions of Test
250-Volt Flexible Cords	1,500 volts	On the insulated core at manufacturer's works after the core has been immersed in water for not less than 12 hours and while still immersed.
Flexible cords with reduced thickness of insulation.	1,500 volts	Between conductors of the finished cord at manufacturer's works in the dry state.

Insulation Resistance.

Determined after one minute's electrification at 500 volts D.C. at or near 20° C.

The minimum insulation resistance values specified in B.S. 7 for 250 volt and medium voltage heavy duty vulcanised rubber insulated cables are given on following page.

*In B.S. 7, 1953, these cables are designated as "Medium Voltage Heavy Duty Cables."

†Alternatively, voltage tests after installation on cables may be made with direct current, when the testing voltage shall be 1·5 times the specified alternating current test voltage.

TABLE No. 13.

MINIMUM INSULATION RESISTANCE VALUES FOR 250-VOLT AND MEDIUM VOLTAGE HEAVY DUTY VULCANISED-RUBBER-INSULATED CABLES.

(B.S. No. 7, 1953).

Nominal Area of Conductor	Number and Diameter of wires (or equivalent strand in flexible cables)	Insulation Resistance for 1,000 yds. at 20° C.
sq. in.	in.	megohms
0·0015	1/·044	2400
0·002	3/·029	2000
0·003	3/·036	1700
0·003	1/·064	1700
0·0045	7/·029	1600
0·007	7/·036	1500
0·01	7/·044	1300
0·0145	7/·052	1200
0·0225	7/·064	1100
0·03	19/·044	1000
0·04	19/·052	900
0·06	19/·064	800
0·1	19/·083	750
0·15	37/·072	700
0·2	37/·083	700
0·3	37/·103	650
0·4	61/·093	600
0·5	61/·103	550
0·75	91/·103	550
1·0	127/·103	500

Spark Testing.

As an alternative to the voltage and insulation resistance tests, spark testing is permitted by B.S. 7. This test, which is largely used, consists of passing the cable core through a fine mesh lined electrode which makes intimate contact with the surface of the insulation. The speed of traverse is such that every point of the cable core is in contact for at least 0·1 second and subjected to a voltage, which varies with conductor size. A fault is shown by a puncture of the dielectric and the machine is arranged so that it is automatically stopped when breakdown occurs.

On referring to the diagram shown in Fig. 11, it will be seen that when a fault in the cables comes under the electrode E, the

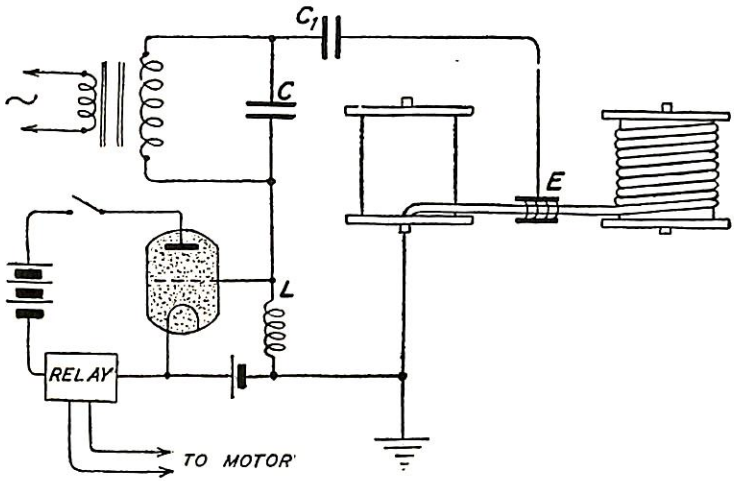


Fig. 11—Spark Testing Diagram.

condenser C discharges through the inductance L, setting up radio frequency oscillations and so causing a rise in voltage across it. The series condenser C_1 limits the current through the cable to prevent undue burning.

A gas-filled triode valve is connected across the inductance L, with the grid biased so that the valve does not discharge under normal running conditions. Any rise in voltage above a predetermined minimum due to high frequencies, causes the valve to discharge and the resultant heavy current in the anode circuit operates the master relay which rings a bell and stops the winding motor.

The following voltages for spark testing are specified in B.S. 7 :—

TABLE No. 14.

VOLTAGE VALUES FOR SPARK TEST.

Type	Test Voltage R.M.S.
Flexible cords with reduced thickness of insulation	3,500 volts
250-*Volt Grade*	
Up to and including 0·0225 sq. in. ...	6,000 volts
Above 0·0225 sq. in. up to and including 0·04 sq. in.	8,000 volts
Above 0·04 sq. in. up to and including 0·06 sq. in.	10,000 volts
Medium Voltage—Heavy Duty Grade	
Up to and including 0·04 sq. in ...	10,000 volts
Above 0·04 sq. in. up to and including 0·06 sq. in.	12,000 volts

7. CURRENT LOADING AND INSTALLATION OF V.R. CABLES.

These are controlled by the Wiring Regulations of the Institution of Electrical Engineers. The current rating of the larger cables is based on a temperature elevation of 30° F. with an ambient temperature of 90° F. For the smaller cables, for which a rating based on temperature elevation would result in an impossibly high volt drop, the rating was earlier based on the fixed value of 4,000 amperes per square inch and, later on, the rated size of the switch plugs, etc., with which the cable was to be used. For ambient temperatures higher than 90° F. reduction factors are given in the Regulations—these, however, apply only for high temperatures; there is no corresponding increase for lower temperatures.

The permissible current ratings for V.R. cables based on above Regulations are summarised on following pages :—

TABLE No. 15.—I.E.E. CURRENT RATINGS* FOR RUBBER, P.V.C. OR POLYETHYLENE INSULATED CABLES (13th Edition, 1st September, 1955).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nominal Cross-Section Area of Conductor	No. and Diameter of Wires	Two Single Core Cables D.C. or Single Phase A.C.		Three or Four Single Core Cables	Four Single Core Cables	One Twin Cable	One Three Core or Four Core Cable	Two Single Core Cables Without Metal Sheath		Three Single Core Cables Without Metal Sheath		Two Single Core Cables Lead or Aluminium Sheathed		Three Single Core Cables Lead or Aluminium Sheathed	
		D.C.	A.C.	Balanced Three Phase A.C.	D.C. or Single Phase A.C.	D.C. or Single Phase A.C.	Balanced Three Phase A.C.	D.C. or Single Phase A.C.		Balanced Three Phase A.C.		D.C. or Single Phase A.C.		Balanced Three Phase A.C.	
								D.C.	A.C.	Flat Formation	Trefoil Formation	D.C.	A.C.	Flat Formation	Trefoil Formation
Sq. Inch		Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.
0·0015	1/044	5	5	5	5	5	5	Rubber Insulated Cables Only				Rubber Insulated Cables Only			
0·002	3/029	10	10	10	10	10	8								
0·003	3/036	15	15	13	13	15	10								
0·0045	7/029	20	20	15	15	20	15								
0·007	7/036	28	28	25	22	28	20								
0·01	7/044	36	36	32	29	36	25								
0·0145	7/052	43	43	39	34	43	30								
0·0225	7/064	53	53	48	42	53	37								
0·03	19/044	62	62	56	50	62	43								
0·04	19/052	74	74	67	59	74	52								
0·06	19/064	97	97	88	78	97	68					†	†	†	†
0·10	19/·083	—	—	—	—	140	98	160	160	155	140	165	165	160	140
0·15	37/·072	—	—	—	—	180	126	205	205	200	185	215	210	205	180
0·20	37/·083	—	—	—	—	218	153	250	250	245	220	260	255	250	220
0·30	37/·103	—	—	—	—	284	199	335	335	325	295	345	335	325	290
0·40	61/·093	—	—	—	—	342	240	425	425	425	360	445	415	410	355
0·50	61/·103	—	—	—	—	394	276	485	480	480	410	500	465	460	400
0·75	91/·103	—	—	—	—	—	—	630	610	610	520	650	570	560	500
1·00	127/·103	—	—	—	—	—	—	780	740	735	630	800	650	640	600
		Cables bunched and enclosed in one conduit, troughing or casing, or bunched in free air or in an open trench.				Cables in free air only installed as defined on Page 107 of the I.E.E. Regulations.									

†See below—rating factors for aluminium sheathed cables

* Above current ratings are extracted from the I.E.E. Regulations for the Electrical Equipment of Buildings—Thirteenth Edition, issued 1st September, 1955

1. The current rating of a fittings wire (3/·020) is 3 amperes.

2. For two or three cables having conductors of cross sectional area exceeding 0·06 sq. inch (19/·064) bunched in troughing or casing, the rating given in columns 9, 10 and 12 (non-metal sheathed cables) or columns 13 to 16 (inclusive) for metal sheathed cables apply, subject to a rating factor of 0·9. For four such cables so installed the ratings given in columns 9 and 10 or 13 and 14 shall be reduced by a factor of 0·9 and by a further factor (for grouping) of 0·8. For larger numbers the ratings given in columns 9 and 10 or 13 and 14 shall be reduced by a factor of 0·9 and by the further factor for larger groups set out below :—

Grouping of Cables, Columns 3 and 4, D.C. or Single Phase A.C.

No. of circuits (Pairs of Cables)	3	5	10
Rating Factor (Applicable to Columns 3 and 4)	0·7	0·6	0·5

Grouping of Cables, Column 5, Balanced Three Phase A.C.

No. of circuits (three cables per circuit or four cables where one is neutral)	2	3	4	6
Rating Factor (Applicable to Column 5)	0·8	0·65	0·6	0·55

Rating Factor for Ambient Temperature.

Ambient Air Temperature	25°C. (77°F.)	35°C. (95°F.)	40°C. 104°F.)	45°C. (113°F.)
Rating Factor	1·13	0·86	0·69	0·47

Grouping of Cables—Columns 7 and 8.

Number of Cables	2	3	4	5
Rating Factor	0·8	0·7	0·65	0·6

Columns 9, 10, 11 and 12.—The ratings for three cables also apply to four cables in a three phase four wire system. For two or more circuits, each installed as defined on page 107 of the I.E.E. Regulations, no reduction in rating need be applied, providing that there is a clearance of at least 6 inches between circuits and that, if the number of circuits exceeds four, they are installed in a horizontal plane. Dispositions of groups of cables in closed trenches or in proximity to metal-work are dealt with in Appendix G of the I.E.E. ratings.

† For Aluminium Sheathed Cables (A.C.).‡

Cross-sectional Area of Conductor	0·1 & 0·15 in.²	0·2 & 0·3 in.²	0·4 & 0·5 in.²	0·75 & 1·0 in.²
Rating Factor :—				
Two or Three Cables in Flat Formation	0·97	0·92	0·84	0·81
Three Cables in Trefoil Formation	1·00	0·96	0·92	0·84

‡ For D.C. circuits, the ratings appropriate to lead-sheathed cables may be applied to aluminium-sheathed cables.

The requirements for installation, broadly speaking, enforce external protection such as conduit or casing for taped and braided cables, but T.R.S. may be used on the surface fixed by suitable clips (with mechanical protection, in positions particularly susceptible to mechanical damage) or may be embedded in plaster. Lead alloy sheathed cables may be run on the surface or embedded in plaster, etc.

8. SYNTHETIC RUBBER-LIKE MATERIALS.

The price of rubber between the two world wars fluctuated violently between a few pence and several shillings per pound and the major part of the world supply was controlled by this country.

These conditions, a growing desire in several countries for self-contained nationalisation together with the colossal stock of armaments built up by Germany and America prior to the second world war, left those two countries with a demand for rubber for which their control currency was inadequate in peace time and these conditions stimulated a demand for synthetic rubber-like materials.

In 1826 Faraday showed that rubber was a hydrocarbon and in 1860 Williams reported to the Royal Society on the preparation of rubber from isoprene—a pure hydrocarbon.

It is generally agreed to-day that rubber is a polymer of "isoprene" a term meaning that it is made up of long strings of isoprene molecules.

In 1910 Lebedev in Russia proved that butadiene could be polymerised to a synthetic rubber.

During 1912 Sir William Perkin and associates such as Matthews and Strange in England produced butadiene from ethyl alcohol while Harries of Germany and Matthews and Strange almost simultaneously patented the polymerisation of butadiene with sodium.

This work formed the foundation of the synthetic rubber industry.

There are two main groups of synthetic rubber materials known as "general-purpose" synthetics, *i.e.*, materials which have rubber-like properties, and "special-purpose" synthetics, *i.e.*, materials having special properties (which excel those of natural rubber) such as fire-resisting, oil-resisting properties, etc.

The four main types are Buna S, Neoprene, Thiokol and Butyl Rubber—during the war period these four synthetics were known in the U.S.A. as G.R.-S, M, P, and I respectively, the prefix G.R. denoting Government Rubber.

Buna S (GR-S).

GR-S is the general purpose synthetic which is the standard material produced in the greatest quantities, mainly for tyres and the insulation of wires and cables.

It is a co-polymer of butadiene and styrene.

The butadiene/styrene ratio can be varied over a considerable range but a 3 : 1 butadiene/styrene ratio was standardised during the war period in order to provide the maximum quantity of general-purpose synthetic rubber.

The term Buna S was originally used in Germany, "Bu" being the first syllable of butadiene, "Na" from natrium (the classical name of sodium originally used as a catalyst in the polymerization of butadiene) and the letter "S" for styrene.

The big advantage of GR-S is that it can be compounded, processed and vulcanised with the standard equipment used for natural rubber, and unlike the majority of synthetics GR-S is used both for insulating and sheathing electric cables.

Neither butadiene nor styrene are natural products and so both these materials have to be obtained synthetically. Butadiene is a gas at normal temperature (above $-5°$ C.) and it can be obtained from direct mineral sources (petroleum or coal) or from indirect mineral sources (acetylene).

Alcohol obtained from agricultural raw materials such as corn (and other grain) is another source.

Styrene is prepared by a process (first discovered by *Berthelot*) which consists of the removal of hydrogen from ethyl benzene, and ethyl benzene, in turn, is made by combining ethylene and benzene. Both ethylene and benzene are obtained from petroleum.

The manufacture of GR-S is (briefly) as follows :—

Liquid styrene and the gas butadiene (which is stored in liquid form under pressure) are fed in a solution having approximately three parts of butadiene to one of styrene and this solution is then emulsified or whipped into small droplets in a water solution.

The temperature is then raised and a catalyst is added to bring about polymerization, *i.e.*, the linking up of the molecules to form long chains in the manner which is characteristic of synthetic plastics.

As the polymerization process proceeds, the material becomes more viscous and more rubber-like.

The droplets are now converted to the form of solid flocs or crumbs of synethetic rubber, which rise to the surface of the solution and are screened off.

The flocs are then washed, the excess water is pressed out and the material is dried and baled.

Butadiene-Styrene Rubber is to-day obtained from the Canadian plant at Sarnia under the name of Polysar S.

Polychloroprene (P.C.P.), Neoprene, or GR-M.

GR-M (Government Rubber-Monovinyl acetylene) was the first commercially developed "special purpose" synthetic rubber.

The early product had many disadvantages and therefore later and more satisfactory types were developed, *i.e.*, Neoprene E, Neoprene G, Neoprene GN, etc.

Neoprene is polymerised chloro-butadiene.

Chloro-butadiene is a colourless liquid (B.P approximately 60° C.) which polymerizes into a solid varying from a pale yellow to a darkish brown colour.

Neoprene mixes have one important difference from the butadiene rubbers in that sulphur is not necessary to transform it from the plastic non-elastic stage to the elastic non-plastic stage.

About 2,500 tons of Neoprene per annum are used in Great Britain despite the restrictions imposed on the importation of this material—it has not so far been manufactured here.

Neoprene is used mainly as a sheathing material by the cable industry because of its excellent fire-resisting properties resulting from the high chlorine content (nearly 40%) ; it is also resistant to ozone (corona checking), oil and sunlight and it can be processed in the same way as rubber.

The dielectric characteristics of Neoprene are poor, but S.W. Melsom* has shown how a composite rubber/Neoprene insulant made up in three layers (the first of which is a rubber compound to provide good electrical properties and the outer two layers are Neoprene to provide mechanical protection and fire resistance) can be used to obtain special properties for certain specific conditions.

This composite dielectric is covered by B.P. 499, 908.

B.S. 708, 1950 (Trailing Cables for Mining Purposes) specifies a P.C.P. sheath which will not support combustion† and resistance of the sheath to abrasion and cutting is ensured by the inclusion of a high proportion of carbon black.

P.C.P. is also specified as a sheathing material in B.S. 937 (Flexible Cords for Miners Cap Lamps) because of its resistance to perspiration.

P.C.P. is of particular interest for aircraft cables ; it is important to appreciate that the cabling of a large modern aircraft represents probably the largest single component of weight in the electrical system.

*Melsom, S. W., "Electric Cables and Fire Risks," *Journal* Inst. of Elec. Engs., Vol. 87, page 521.

†B.S. 708, 1950, page 29, "Resistance to Flame" test.

During the latter part of the war P.V.C. cables were used for aircraft wiring, the plastic insulation being protected by woven glass suitably identified by colour but this construction was superseded by the so-called "Pren" type cable sponsored by the Ministry of Supply.

Pren cables have their conductors made up of fine wires (0·006 0·0076, 0·012 and 0·018 inch diameter) in order to obtain a high degree of flexibility, then a thin glass braiding is applied and finally, for single core cables a layer of vulcanised P.C.P. insulation.

Single core Pren cables (*i.e.*, Unipren) are coloured blue except in the smaller sizes and they have the current rating printed in black periodically along their length.

Multicore cables (Dupren, Tripen, etc.) are also available and these may be covered with an outer layer of Neoprene (Duprensheath, etc.).

For larger sizes of cable above 35 amp rating, aluminium conductors are available as an alternative to copper.

These "Prenal" cables show a further weight saving and are distinguished by being coloured yellow.

Fig. No. 12 (due to Flack*) shows the weight and current density in standard sizes of Pren and Prenal cables. The approximate weight of P.V.C. cables is also shown dotted.

Thiokol or GR-P.

Thiokol (GR-P) was discovered in the early 1920s by Dr. J. C. Patrick (U.S.A.) while he was trying to develop a new anti-freeze fluid and it was introduced commercially in 1929.

The chemical reaction involved in the manufacture of Thiokol synthetic rubber is that between sodium polysulphide and ethylene dichloride and the basic raw materials required are ethylene, sulphur and salt.

To-day hundreds of different types of Thiokol have been developed which differ in physical properties and form.

The primary importance of Thiokol synthetic rubbers is their freedom from attack by petroleum products and solvents while they are also practically unaffected by ozone and sunlight, but Thiokol has poor physical properties and tends to be inflammable.

For these reasons Thiokol mixes which were used by the cable industry in the form of protective sheathings have become superseded by a suitably compounded Neoprene sheathing mix.

Butyl Rubber or GR-I.

Butyl rubber (GR-I) is a polymer of isobutylene (and small quantities of other diolefines such as isoprene or butadiene) which

*"Electricity and Aircraft," D. C. Flack. *The Electrical Journal*, No. 3938, Vol. CLI, No. 23, 4th December, 1953.

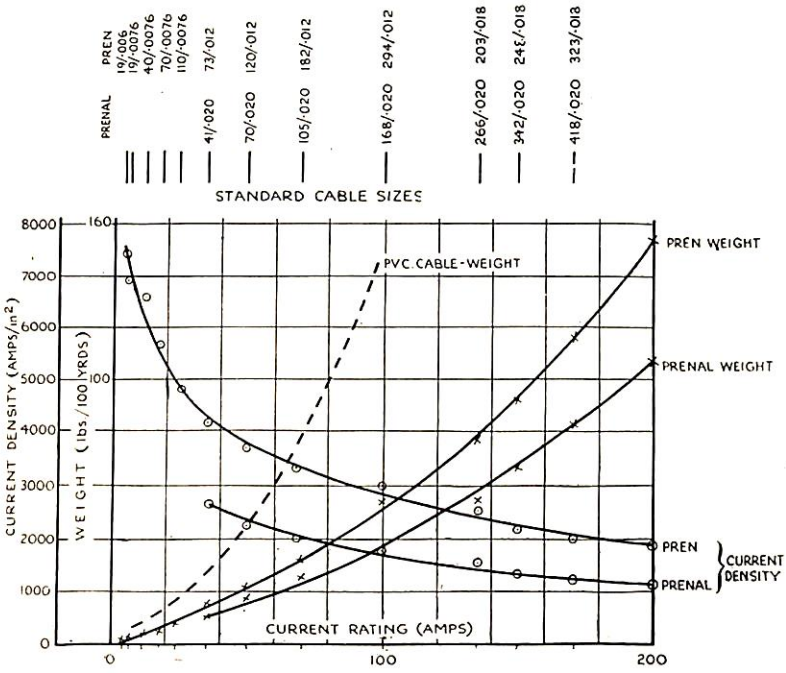


Fig. 12—Graph showing weight and current density in standard sizes of Pren and Prenal cable The approximate weight of p.v.c. cable is also shown dotted.

was discovered by the Standard Oil Co. of New Jersey, who control the process.

Isobutylene (a by-product in petroleum cracking) is a gas at ordinary pressures and at temperatures above $-6°$ C.

The processing of butyl rubber and its electrical characteristics are comparable with that of natural rubber ; its resistance to acid is very good but it is attacked by many solvents and its physical properties are lower than those of natural rubber.

It is known that butyl rubber is being used for insulating cables in the United States,* and with this type of insulation a maximum conductor temperature of 80° C. is permitted by American regulations.

Silicone Rubber.

Arising out of the work by Kipping at Nottingham University College it has recently been appreciated that since silicone rubber may be regarded as a semi-organic compound it should be possible, assuming that a long chain structure could be built up, to produce a rubbery material which could be anticipated to have a high degree of heat resistance.

The polymerization was successfully achieved to give a vulcanisable product in which the backbone of the chemical chain consists of silicon-oxygen linkages ; the resultant product although extremely weak mechanically† and needing some form of external protection, nevertheless possesses an excellent degree of heat resistance and it can be operated for long periods at temperatures of the order of 120° C. - 150° C.

Furthermore, operation up to 200° C. is considered practicable under certain conditions but with considerably reduced expectation of service life.

The ultimate raw materials for a typical silicone could be sand (silicone oxide), coke, marsh gas or wood spirit, magnesium (mined as an ore or possibly derived from sea water) and salt.

Silicone rubber is marketed by one supplier (*i.e.*, Midland Silicones, Ltd.) under the trade name of "Silastic."

Wentworth‡ has summarised some physical and electrical properties of the various grades as follows :—

* Information obtained indicates that the U.S.A. cable industry used approximately 3,300,000 lbs. of *crude* butyl polymer in 1954 which, roughly, would amount to about 8,000,000 lb. of butyl-rubber compound.

†Bass, S. L., "Proceedings of the Second Rubber Technology Conference." Inst. of the Rubber Industry, 1948, page 20.

‡Wentworth, V. H., "Synthetic Rubbers." *The Electrician*, 9th Feb., 1951.

TABLE No. 16.

TYPICAL PHYSICAL AND ELECTRICAL PROPERTIES OF SILASTIC.

Grade	Density at 25° C.	Hardness Shore A Scale	Tensile Strength p.s.i.	Elongation at break per cent.	Water absorption after 7 days at room temperature M_g/sq. inch	Dielectric Constant at 10^6 cycles/sec.	Power Factor per cent at 10^6 cycles/sec.	Dielectric Strength Volts/mil. at 30 mils.
150	1·9	45-55	400	300	47	5·3	1·8	500
160	2·1	55-65	600	200	17	8·1	2·5	500
161	2·1	55-65	600	200	22	—	—	—
167	2·0	60-70	600	110	25	9·0	0·2	500
180	1·6	75-85	700	75	7	4·4	0·4	650
181	1·3	75-85	650	90	15	3·2	0·5	800

Vulcanisation : 5 min. at 260° F. and 4 hours at 480° F.

Other interesting properties* of the silicone rubbers are that they remain flexible to quite low temperatures of the order of $-70°$ C.; they are unaffected by oxygen and appear to have extremely good resistance to weathering.

Synthetic v. Natural Rubber.

The implication that substitute materials are inferior is generally accepted but it is erroneous since the war has proved that several types of synthetic rubbers have special characteristics which make them eminently suitable for certain services.

It has always been appreciated that natural rubber has many limitations and the combined labours of chemists, technicians and engineers are showing that in the post war era the application of both natural and synthetic rubbers will probably be complementary rather than substitutive.

Terminology Relating to Synthetic Rubber and Thermoplastics.

In recent years the term "synthetic rubber" has been very loosely used and is difficult to define.

Some materials, such as Perbunan resemble rubber closely while P.V.C. and P.I.B. are quite rubbery, yet they are themoplastic and cannot be vulcanised.

Can they all be termed synthetic rubbers?

Some types of jellies and waxes have rubber-like properties.

Natural rubber varies in its chemical constitution and no complete success has been achieved in its synthesis. Moreover, none of the synthetic materials possess all the properties of rubber.

The term "rubber" is to-day an unsatisfactory one and Barron† has suggested the term "elastics" instead.

He has classified elastics as follows :—

Natural Elastics.

(1) Natural Rubber.

(2) Gutta Percha, Balata.

Synthetic Elastics.

(1) Elastomers. Unsaturated materials based on butadiene which are unvulcanisable, *e.g.*, Buna S, Perbunan, Neoprene.

(2) Elastomers. Saturated materials based on olefines, *e.g.*, P.I.B.

* D. C. R. Miller, "The Properties and Applications of Silicones," *The Engineering Journal*, Vol. 38, No. 10, October, 1955, pp. 1339-1349.

†Barron, H., "Modern Synthetic Rubbers" (Book), Chapman and Hall.

(3) Ethenoids. P.V.C., Acrylic esters.
(4) Thioplasts. Thiokols.
(5) Elastoplasts. Plastics which have a limited phase of electrical properties, *e.g.*, polystrene, cellulose esters.

9. POLYVINYL CHLORIDE (P.V.C.) INSULATED CABLES.

Thermoplastic insulants and, in particular, polyvinyl chloride (P.V.C.) had been developed before the last war but mainly on an experimental basis. The polymer is a synthetic material derived generally from acetylene and can be produced in a number of grades, depending on the polymerisation processes adopted. The polymer is in the form of a white powder, which is odourless, tasteless, chemically inert, non-inflammable and insoluble at ordinary temperatures to any known liquid.

The essential characteristics, viz., the electrical properties of all plastic materials, is that the molecular construction should be of long chain molecules without groupings which result in polarisation. Actually, vinyl chloride from which P.V.C. is derived, contains a chloride atom—a polar material which to an extent adversely affects the electrical properties ; on the other hand, it notably improves the fire-resisting characteristics.

For cable manufacture, however, the polymer must be compounded with a plasticiser, the function of which is to "gell" the polymer and to render it plastic over a wide temperature range. The characteristics of the polymer are largely affected by the plasticiser and many grades of material have been produced with widely differing characteristics. There are now, however, several standard grades, which can be made to conform to specifications for cables for use over a wide range of temperature.

P.V.C. has not all of the qualities of vulcanised rubber ; it is inferior in respect of elasticity and recovering from stretching, and being a plastic, it is liable to plastic flow under conditions of high temperature and pressure and also tends to harden and shrink with volatilisation of the plasticiser. Also, its insulation resistance is very much lower than that of rubber. On the other hand, a suitable compound, installed and operated with regard to the properties of the material, offers advantages over rubber in that it is inert to oxygen, and relatively so to oils and many acids and alkalis. Therefore, providing that the temperatures are reasonable and that it is not subject to undue pressure in installation, P.V.C. is a notable competitor with rubber.

Amendments have been issued to B.S. 7, 1946, Specification, and various other Standard Specifications for V.R. Insulated Cables permitting the use of P.V.C. cables as an alternative type to V.R. insulated cables for copper sections up to and including 19/064 conductor sections (0·06 sq. in.)—a British Standard (B.S. 2004,

1953)* now being revised, dealing specifically with P.V.C. cables has also been published.†

Installation and Permissible Current Rating for P.V.C. Cables.

The I.E.E. Regulations recognise the use of P.V.C. cables. With few exceptions, existing rubber cable practice is suitable for P.V.C. cables. Owing, however, to the intrinsic characteristics of P.V.C. the protection used for V.R. insulated cables will not always be necessary and may be omitted, *e.g.*, P.V.C. cables without braid can be drawn direct into a sound and well erected conduit system, although where friction is likely a braided and compounded cable may be preferable.

The number of cables in a given conduit (refer Appendix No. 12) will be the same as for V.R.T.B. and C. cables (*vide* I.E.E. Regulations).

A lead sheath to give protection against atmospheric conditions is not necessary for P.V.C. under normal conditions. For installation immediately outside buildings P.V.C. insulated and P.V.C. sheathed cables can be used.

Terminating arrangements are very much the same as for V.R. cables except that sealing the ends against the ingress of oil is not so important as for rubber. Acids or other reagents likely to attack the conductor must, however, be guarded against by adequate sealing. Current ratings of P.V.C. cables are the same as for V.R. cables installed under identical conditions. P.V.C. cables should not be considered as a substitute for V.R. cables—with both V.R. and P.V.C. cables readily available P.V.C. will find its own level on technical and economic considerations.

10. POLYTHENE INSULATED CABLES.

Polythene (also referred to by the chemical name polyethylene) is a straight chain polymer derived from ethylene. Polythene, a British development was originally discovered by I.C.I. in the early 1930s. For production purposes, special apparatus had to be built capable of withstanding pressures up to 2,000 atmospheres.

It was discovered that at pressures over 1,000 atmospheres ethylene polymerised into a tough thermoplastic which was named "polythene." The solid is built up of crystalline and amorphous material—one cannot be separated from the other—the relative proportions varying with temperature from 75% crystalline content at 20° C. to 100% amorphous at the melting point (110°-115° C.). This change in structure results in a large coefficient of expansion.

* Refer also to B.S. 2571, 1955, "Flexible Polyvinyl Chloride (P.V.C.) Extrusion Compounds."

† A revision, B.S. 2004, 1955, has just been issued and the most important change is that copper conductors are now specified as the preferred standard. Otherwise, apart from changes in the tables due to the preference for tinned conductors, and minor editorial amendments, the text is the same as the 1953 edition.

The average molecular weight* of polythene can be controlled during manufacture within narrow limits.

There are four grades of polythene commercially available, 2, 7, 20 and 70, the average molecular weight varying from 13,000 to 19,000. Recent trends in the manufacture of polythene have resulted in increasing use being made of grade 2 for the production of electric cables. The electrical properties of polythene are extremely good, *e.g.*, very low power factor at all frequencies, low permittivity and high resistivity.† (Refer Table No. 17). Its electrical properties render it particularly suitable for high frequency cables, for which it has a large use.

TABLE No. 17.

ELECTRICAL PROPERTIES OF POLYTHENE.

Characteristic	
Power Factor (Tan δ) at 20° C.	0·0002 — 0·0003 (Frequency 50 — 10^{10} C/S)
Permittivity	2 — 3 (Frequency 50 — 10^{10} C/S)
Volume Resistivity	3×10^{17} ohm — cm
Surface Resistivity	10^{11} ohm
‡Dielectric Strength (at 50 C/S at 20° C.)	1000 volt/mil on films of the order of 0·0005″ 360 volt/mil at 210 mils.

Polythene has also been used to a limited extent as a power cable insulant, the general requirements for which can be broadly stated as follows :—

(1) High dielectric resistance.

(2) Low power factor or dielectric loss angle tan δ (this being a measure of the imperfection by which the dielectric departs from theoretical perfection).

* It is now claimed that recently a method has been found of producing polyethylene at atmospheric, or even slightly lower, pressure, whereas pressure as high as 2,000 atm. have hitherto been required. Furthermore, polyethylenes can be made by the new process with molecular weights ranging from 10,000 to 2 million. Refer "Engineer's Digest," Vol. XVI., No. 12, December, 1955.

† The Du Pont Co. of America have recently announced the manufacture of a new material *Hypalon* (Chlorosulphonated Polyethylene) which can be vulcanised, and it has better electrical properties than Neoprene. It is also claimed to be a tough, oil resistant, heat resistant material which may find useful applications in the cable industry if the claims made by the manufacturer are fully justified and the price is economic when compared with available materials.

‡According to Oakes the intrinsic dielectric strength of Polythene is 6000 kV/cm.

(3) High electric strength.
(4) Low thermal resistance, *i.e.*, the ability to dissipate the heat (I^2R losses) generated in the conductor.
(5) Ability to withstand reasonable bending.

The thermal dissipation properties of polythene are better than impregnated paper and for the purpose of computing the current carrying capacity of polythene insulated cables, a value of 450° C./watt/cm. has been used—this compares with 550° C./watt/cm. for high voltage impregnated paper insulated cables. The softening point of polythene is about 108° C. which enables a polythene dielectric to operate at a maximum conductor temperature of the order of 60° C.

In the case of short circuit conditions a maximum temperature of 95° C. is tentatively used (as against 120° C. for impregnated paper) which results in a short circuit rating of about 85% of the corresponding impregnated paper insulated metal sheathed cable—the permissible short circuit rating of polythene insulated cables is, however, being given careful consideration at the present time.*

11. POLYSTRENE.

Polystrene is the generic name given to polymers of styrene.

Styrene was first produced by heating Storax in 1831 and its polymerisation in the presence of sunlight and heat was noted in 1839.

Processes of making stryene from ethyl benzene were discussed in France by Berthelot in 1869 and in 1911 patents were published by Matthews of London recording the insulating properties of polystrene.

Stardinger published results of work on polmerisation during and after 1926 and general industrial research in Great Britain and the U.S.A. started in 1933. By 1937 polystrene was being produced commercially in Great Britain and the U.S.A.

At room temperature Polystrene is a rigid and glass-like material although when heated to about 180° F. it tends to become elastic and rubbery in nature and at this temperature it can be moulded and extruded.

* Two plastic materials of interest for high temperature requirements are Polytetrafluoroethylene (P.T.F.E.) and Polychlorotrifluoroethylene, which may be regarded as Polythene, in which four hydrogen atoms have been replaced by four fluorine atoms or one chlorine and three fluorine atoms. Polychlorotrifluoroethylene (known as Kel. F. in America) may be processed in the conventional way as Polythene and P.V.C. although higher temperatures are necessary for extrusion ; P.T.F.E., however, requires special machinery and handling techniques.

At present the price of P.T.F.E. is high and its high specific gravity tends to make its price per unit volume even more unfavourable.

It is also possible to develop a fairly high degree of flexibility in Polystrene when in the form of relatively thin films (and threads) by a mechanical process in which the molecules are aligned by subjecting the material to a stretching process (*e.g.*, extrusion in the desired form followed by stretching in the plastic state).

With above technique, Polystrene, known by the trade name of "Styroflex," can be prepared as flexible threads and tapes suitable for use in the manufacture of insulated cables.

Pollitt and Jesson* have summarised the physical and electrical characteristics of Polystrene as follows :—

TABLE No. 18

PHYSICAL AND ELECTRIC CHARACTERISTICS OF POLYSTRENE

Characteristic		
Specific Gravity		1·05 - 1·06
Brinell Hardness		20 - 30
Refractive Index		1·668
Water Absorption (%)		Nil to 0·02
Tensile Strength (lb./sq. inch)		6,000 - 7,000
Specific Dielectric Resistance at 20° C. (ohms/cm^3)		1×10^{18}
Specific Inductive Capacity	50 cycles to 0·75 megacycles at 80% R.H. and 20° C.	2·4 - 2·6
Power Factor		0·0002 - 0·0003
Breakdown Voltage (volts/mil)		12,000

Polystrene has also been used in connection with the jointing of super-voltage cables. The Styrene† joint is a design in which there is no liquid-oil compound.

The insulation consists of hand applied paper tapes impregnated and coated with styrene which slowly polymerises into a solid mass and forms a complete barrier.

The radial thickness of insulation used is only 10% greater than the machine-applied insulation on each conductor so that a very compact joint is produced.

*Pollitt, W. F. O., and Jesson, F. G. R. "Synthetic Rubbers and Plastics" (III), Part 2. "Distribution of Electricity" No. 152, Vol. XVI, Oct., 1943, page 172.

†Konstantinowsky, K., and Lee, E. C. "Styrene Joints and Terminations." Paper No. 217 C.I.G.R.E., Paris, 1950.

12. NYLON.

Nylon—polyamide resin—is prepared by a combination of hexamethylene diamine and adipic acid from which eventually nylon polymer is produced, but variations of both acid and amine are introduced by different manufacturers.

From the cablemakers' viewpoint nylon is of interest because advantage can be taken of the very tough abrasion resisting properties of extruded forms, and applications to cables are under service tests. Its probable use is in the form of very thin extruded coverings, about 0·005″ thick, over polythene or other conventional insulants to provide the mechanical protection in place of textile braidings. The insulating properties of nylon are not of primary interest since they deteriorate considerably when nylon absorbs moisture.

ACKNOWLEDGMENTS.

References to, and extracts from, British Standards are given by permission of the British Standards Institution, 2 Park Street, London, W.1, from whom copies of the official specifications may be obtained.

The author also wishes to express his thanks to the Institution of Electrical Engineers for permission to quote data from the recently published 13th edition of the "I.E.E. Regulations for the Electrical Equipment of Buildings."

USEFUL REFERENCES.

I.—General.

WARREN H., *Electrical Insulating Materials* (Book), Ernest Benn, Ltd., 1931.

QUAYLE, J. C., and JONES, P., "Dielectric Heating," *Electrical Review*, September 14th, 1945, p. 363.
—"Glass Insulation," *Electrical Review*, November 1st, 1946, p. 679.

WOOLFSON, M. G., "Statistical Methods in Wire and Cable Processing," *Electrical Engineering*, Vol. 67, No. 7, July, 1948, p. 637.

WARNER, A. J., "Electrical Properties of Plastics," *Electrical Communication*, Vol. 26, No. 1, March, 1949.

FAUCETT, HOUPIS, and LIEBINGER, "A Survey of Insulation Practices" : Engineering Equipment Station Circular Series, No. 57, 1949, University of Illinois, Urbana, U.S.A.

HOLLINGSWORTH, P. M., "Cables Sheathed in Aluminium Development in Great Britain," Paper No. 203, Paris, 1950, C.I.G.R.E. Meeting.
—*Electrical Engineers Reference Book*, George Newnes, Ltd. (8th Edition, 1955).

GRAHAM, R. C., "Cable Insulation for Chemical Plants." Paper read at A.I.E.E. Winter General Meeting, January, 1950.

LATHAM, JONES, and CARTER, "Cable Insulations for Chemical Plants." Paper presented to American Institute of Electrical Engineers, 1950. Winter General Meeting, New York.

DUFLOS, J., and MATHWET, P., "Modern Insulating Materials and Possible Uses of Glass Fibre." *R.G.E.*, Vol. 61, pp. 22-26, January, 1952.

BARNES, C. C., "Copper, Lead and Aluminium for Electric Cables," *Electrical Industries*, Vol. 52, No. 8, p. 239, August, 1952.

GIARO, J. A., "Present State of Cables for Mines," *A.I.M. Bulletin*, Vol. 64, pp. 131-153, March, 1951.

THOMAS, A. MORRIS, "Trends in Insulation Reliability," *Electrical Review*, Vol. CXLVII, No. 3807, 10th November, 1950, p. 751.

WENTWORTH, V. H., "P.T.F.E.," *The Electrician*, 1st August, 1952, p. 337.

WHITEHEAD, S., "Progress in Dielectrics," *Electrical Review*, Vol. 153, No. 24, p. 1309, 11th November, 1953.

RIDPATH, C. H. E., "Aluminium for Insulated Cables," *Electrical Times*, Vol. 122, No. 3386, p. 957.

MOSES and WHITNEY, "New Applications for Thermalistic Insulation," *Westinghouse Engineer*, September, 1953, p. 167.

SNADOW, R., "Insulating Materials," *Electrical Times*, Vol. 123, No. 3198, p. 331.

CORNELL, L. W., "Polytetrafluorethylene—Its Properties and Uses," *Mechanical Engineer*, November, 1953, p. 883.
—"New Principles, New Materials," *Power Engineering*, January, 1953, p. 76.

MILDNER, WILSON and COOKE. Plastics in the Telecommunication Cables Field. Plastics Progress. British Plastics Convention, 1953.
—"Symposium of Papers on Insulating Materials," *Journal of Institution of Electrical Engineers*, Vol. 100, Part II A, Nos. 1953.

II.—Natural Rubber.

NAUNTON, W. J. S., "Anti-oxidants." Inst. Rubber Industry Trans., Vol. V, No. 5, February, 1930, p. 317.

DUNSHEATH, P., "Quality in Rubber Cables," *Mining Electrical Engineer*, May, 1934, p. 361.

ROSCH, S. J., "Current Carrying Capacity of Rubber Insulated Cables." American Institute Elec. Engs., Trans., Vol. 57, No. 3, March, 1938, p. 155.

HUTCHINGS, E. E., and WHITEHEAD S., "Current Ratings of Vulcanised Rubber Insulated Cables Run in Steel Pipes." Electrical Research Assoc. Report, F/T145, 1941.

BARNES, C. C., "Rubber and the Engineering Industry," I.E.E. Students' Quarterly Journal, Vol. 14, No. 54, December, 1943.

BARRON, H., *Modern Rubber Chemistry* (Book), Hutchisons, 1947.

BASS, S. L., "Proceedings of the Second Rubber Technology Conference." Institute of the Rubber Industry, 1948, p. 20.

General Specifications for Wire and Cable with Rubber and Rubber-Like Insulations. (American) Insulated Power Cable Engineers' Association.

"Conduit Capacity for V.R.I. Cables," *Electrical Times*, Vol. 124, No. 3224, p. 330.

WENTWORTH, V. H., "Natural Rubber," *The Electrician*, 8th December, 1950, and 5th January, 1951.

B.S. 903, 1950, "Testing Vulcanised Rubber."

KERCKHOVE, M. van der., "The Quality of Rubber Insulated Cables in 1950." *A.I.M. Bulletin*, Vol. 64, pp. 11-29, January, 1951.

TUNSTALL, H. A., "Rubber," *Distribution of Electricity*, No. 201, Vol. XXVI, November, 1953, p. 390.

DIXON, N., "Electrical Cables, Wires and Rubber Insulation." Chapter 17, *History of the Rubber Industry* (Book), W. Heffer and Sons, Ltd.

O'KEEFE, P., Properties and Applications of Electrically Conductive Rubber Materials and Methods, Vol. 37, No. 4, April, 1953.

TEW, H. J., "Continuous Vulcanisation of Rubber Cables," *Distribution of Electricity*, No. 200, Vol. XXVI, September, 1953.

DYKES, J. B., "The Latex Process of Wire Covering," *Distribution of Electricity*, No. 200, Vol. XXVI, September, 1953.

III.—Synthetic Rubber-like Materials.

BARRON, H., *Modern Synthetic Rubbers* (Book), Chapman and Hall, Ltd., 1943.

WHALLEY, M. E., "Rubber Substitutes for Cable Insulation."

NATIONAL RESEARCH COUNCIL OF CANADA, *Report N.R.C.* No. 1139, June, 1943.

SCHATZEL, R. A., *Synthetic Rubbers in the Wire and Cable Industry*. Published by the American Society for Testing Materials. Philadelphia Pa (1944).

WENTWORTH, W. H., "Synthetic Rubbers," *The Electrician*, 9th February, 1951.

SNADOW, R., "Insulating Materials—Their Thermal Classification," *Electrical Times*, Vol. 123, No. 3198, 1953, p. 331.

HAYDEN, J. D., "High Temperature Silicones," *Electrical Review*, Vol. 153, No. 7, 14th August, 1953, p. 330.

FLACK, D. C., "Electricity and Aircraft" (Pren Cables), *Electrical Times*, No. 3938, Vol. CLI, No. 23, p. 1832.

EVANS, B. B., "A Glance at the Silicones," *Distribution of Electricity*, No. 202, Vol. XXVI, January, 1954.

—"Silicones and Insulation," *Electrical Times*, Vol. 123, No. 3192, 8th January, 1953, p. 47.

IV.—Polyvinyl Chloride (P.V.C.).

BARRON, H., "Plasticises and Their Applications," *Plastics*, October, 1943. Vol. VII, p. 77.

TUNSTALL, H. A., "Extruded Plastics Coverings for Electric Wires and Cables." Trans. Plastics Institute Vol. XVIII, No. 33, July, 1950.

WENTWORTH, V. H., "Plastics—P.V.C.," *The Electrician*, 13th April, 1951.

WHITE, F. T., "Thermoplastics in the Cable Industry," *Distribution of Electricity*, No. 186, Vol. XXIII, May, 1951, p. 430.

MEYERS, A. L., "Plastic Insulated Land Communication Cables." *British Institute of Radio Engineers*, Vol. II, No. 12, December, 1951, p. 556.

THOMSON, A. G., "Polyvinyl Chloride," *Electrical Times*, 25th December, 1952.

—"P.V.C. Pressure Tubing," *Electrical Times*, 10th April, 1952, p. 674.

MATTINGLEY, F., "Developments in the Use of Polyvinyl Chloride Wiring Cables." *Telcon House Magazine*, No. 22, p. 8.

B.S. 2004, 1953, "Polyvinyl Chloride Insulated Cables and Flexible Cords for Electric Power and Lighting (250 Volts only)."

V.—Polythene.

BARRON, H., "Substitution Among Materials Used for Cable Insulation," *G.E.C. Journal*, August, 1942, Vol. XII, No. 2.

BARRON, H., DEAN ,J. N., and SCOTT, T. R., "Thermoplastic Cables," *Journa Inst. of Elec. Engs.*, Part II, August, 1944.

WILLIS-JACKSON and FORSYTH, J. S. A., "The Development of Polythene as a High Frequency Dielectric," *Journal Inst. of Elec. Engs.*, Vol. 92, Part III, No. 77, March, 1945, pp. 23-31.

BARRY, W. C., "Synthetic Rubber and Plastics—I," *Distribution of Electricity*, 1943, p. 70.

TUNSTALL, H. A., "Synthetic Rubber and Plastics—II," *Distribution of Electricity*, 1943, p. 93.

POLLETT and JESSON, "Synthetic Rubber and Plastics—III," *Distribution of Electricity*, 1943, p. 142.

VERT, J., "Modern Plastics for Insulation," *British Plastics*, November, 1943.

WENTWORTH, V. H., "Plastics—Polythene," *The Electrician*, 9th March, 1951.

HUMPHRIES, E. D., "Polythene Insulated High Voltage Power Cables," *Telcon House Magazine*, Issue No. 13, page 1.

FLOOD, J. E., "Composite Insulated Wire Constructions Employing Polythene and Nylon." *Wire and Wire Products*, Vol. 26, 1951, pp. 1040, 1081-3.

—"First Plastic Telephone Cables in Denmark," *Electrical Journal*, Vol. 30, January, 1953, p. 372.

DEL MAR, W. A., and MERRELL, E. J., "Polyethylene for Power Cables." Habershaw Cable and Wire Division, New York, U.S.A.

CROFT, P. J., "Polyethylene—Application to Power and Control Cable in Canada and England." Canada Wire and Cable Co., Ltd.

MARBANER and SMITH, "Mechanical, Electrical and Physical Properties of Polyethylene." Paper read to American Institution of Electrical Engineers. Cleveland, Ohio, October 22nd, 1951.

WALDER, V. T., "Polythene for Wire and Cable," *Electrical Engineering*, 1952, Vol. 70, page 59.

COOKE, E. I., "Physical Properties of Flame-Retardant Polythene," *British Plastics*, January, 1953.

REDBELL, D. S., WHITEHEAD, J. B., and MILLER, C. F., "Positive D.C. Corona Polyethylene Insulated Wire in Air," *Journal of the Electrochemical Society*, Vol. 101, No. 2, February, 1954, p. 91.

—"Polyethylene ; Ready for a Boom," *Oil and Gas Journal*, May 9th, 1955.

CHIRNSIDE, R. C., "Plastics—A Decade of Progress," *G.E.C. Journal*, Vol. 22, No. 3, July, 1955, pp. 172-182.

APPENDIX No. 1.

CALCULATED CONDUCTOR AREAS.

(Stranded Circular Conductors).

Nominal Conductor Area and Conductor Stranding		Conductor Diameter		Calculated Conductor Area			Nominal Weight of Conductor		Nominal Conductor Area and Conductor Stranding	
Sq. In.	Inch	Inch	mm.	Sq. In.	Sq. mm.	Circ. Mil.	Lb. per 1,000 Yds.	Kilograms per Kilometer	Sq. in.	Inch
0·002	3/·029	0·062	1·57	0·001943	1·2537	2,474·0	23·4	11·60	0·002	3/·029
0·003	3/·036	0·078	1·98	0·002994	1·9316	3,812·0	36·0	17·85	0·003	3/·036
0·0045	7/·029	0·087	2·21	0·004546	2·9329	5,787·9	54·4	27·00	0·0045	7/·029
0·007	7/·036	0·108	2·74	0·007005	4·5197	8,919·0	83·8	41·55	0·007	7/·036
0·0145	7/·052	0·156	3·96	0·01462	9·432	18,613·0	174·9	86·73	0·0145	7/·052
0·0225	7/·064	0·192	4·88	0·02214	14·284	28,188·0	264·9	131·4	0·0225	7/·064
0·04	19/·052	0·260	6·60	0·03960	25·548	50,416·0	475·5	235·8	0·04	19/·052
0·06	19/·064	0·320	8·13	0·05999	38·701	76,375·0	720·3	357·2	0·06	19/·064
0·10	19/·083	0·415	10·54	0·1009	65·10	128,470·0	1,211·0	600·5	0·10	19/·083
0·15	37/·072	0·504	12·80	0·1478	95·36	188,200·0	1,776·0	880·8	0·15	37/·072
0·20	37/·083	0·581	14·75	0·1964	126·71	250,070·0	2,360·0	1,170·0	0·20	37/·083
0·25	37/·093	0·651	16·53	0·2465	159·02	313,850·0	2,963·0	1,470·0	0·25	37/·093
0·30	37/·103	0·721	18·31	0·3024	195·10	385,020·0	3,635·0	1,803·0	0·30	37/·103
0·40	61/·093	0·837	21·25	0·4064	262·21	517,440·0	4,886·0	2,423·0	0·40	61/·093
0·50	61/·103	0·927	23·54	0·4985	321·60	634,670·0	5,994·0	2,973·0	0·50	61/·103
0·60	91/·093	1·023	25·98	0·6062	391·11	771,800·0	7,290·0	3,615·0	0·60	91/·093
0·75	91/·103	1·133	28·78	0·7435	479·69	946,600·0	8,942·0	4,435·0	0·75	91/·103
1·00	127/·103	1·339	34·00	1·0376	669·35	1,321,000·0	12,481·0	6,190·0	1·00	127/·103
1·25	127/·112	1·465	36·98	1·2269	791·60	1,562,200·0	14,757·0	7,316·0	1·25	127/·112
1·50	169/·107	1·605	40·76	1·4900	961·20	1,897,000·0	17,924·0	8,890·0	1·50	169/·107

APPENDIX No. 2.*

PERSULPHATE TEST FOR TINNED COPPER WIRE.

(B.S. 7, 1953, Specification).

Any part of a coated conductor shall satisfy the following tests :

Preparation of Test Specimens.

(i) The insulation and coverings shall be removed from the conductors of the test samples (length as Column 4 of Table 1) by any method which does not cause injury to the coating, *e.g.*, the insulation may be loosened from a stranded conductor by drawing a solvent and/or oil up the interstitial spaces of the conductor.

(ii) Two groups of specimens, each comprising the number shown in Column 5 of Table 1 shall be extracted from the cable and marked 4 cm. from each end by means of a grease pencil or in some other manner which will not cause damage to the coating.

The groups shall be composed of wires selected at random from the various cores in the case of multicore cables.

(iii) Each test specimen in the case of single conductors, or each group of 3, 5 or 10 test specimens in the case of multiple conductors, shall be wound into one helix upon a smooth mandrel in such a manner as to ensure no twisting moment being imparted to the wire.

Such portions of the test specimens as are necessary to lead up to the 4 cm. ends and provide for their projection above the surface of the testing solution in which the specimens are to be immersed, shall not be formed to the mandrel, but shall be suitably bent for the purpose. Such bending, however, shall not entail a radius of less than half the diameter of the mandrel used to produce the helix.

TABLE 1.

TEST SPECIMEN FOR PERSULPHATE TEST.

1	2	3	4	5	6	7
Test Samples				Test Specimens		
Diameter and Number of Wires Comprising Conductor			Length (cm.)	Number	Length Between Marks	
Diameter (in.)		Number			For each Specimen (cm.)	Total for each group (cm.)
0·0076		10 or more	58	10	50	500
Above	Up to and including					
0·0076	0·012	6 or more	108	5	100	500
0·012	0·029	3 or more	74·7	3	66·7	200
0·029	0·103	3 or more	41·3	3	33·3	100
0·029	0·103	1	108	1	100	100

The diameters of the mandrels to be used shall be in accordance with Table 2.

*The information given in this Appendix is a short résumé of data given in B.S. 7, 1953, specification—reference should, however, be made to B.S. 7, 1953, for the detailed testing procedure.

TABLE 2.

MANDREL DIAMETERS FOR PERSULPHATE TEST.

Diameter of Wire (in.)		Diameter of Mandrel (in.)
0·0076		0·60
Above	Up to and including	
0·0076	0·010	0·65
0·010	0·012	0·70
0·012	0·018	0·85
0·018	0·029	1·15
0·029	0·036	1·30
0·036	0·044	1·50
0·044	0·052	1·70
0·052	0·064	2·00
0·064	0·072	2·20
0·072	0·083	2·50
0·083	0·093	2·75
0·093	0·103	3·00

(iv) The helix shall be removed from the mandrel by slipping it off endwise without further distortion of the wire.

(v) A cleaning operation shall be carried out after the test helix has been removed from the mandrel and immediately prior to its immersion in the test solution, and the part to be immersed shall not be handled.

Determination of Weight of Copper Dissolved.

The weight of copper dissolved from the wire by the persulphate solution shall be determined colorimetrically by comparison with the standard colour reagent. The weight is expressed as milligrams of copper per square decimetre of wire immersed.

Standard of Quality.

If the result obtained does not exceed the appropriate value specified in Table 3, the coating shall be regarded as satisfactory.

TABLE 3.

PERMISSIBLE WEIGHT OF COPPER DISSOLVED IN PERSULPHATE TEST.

1	2	3	4	5	6
Diameter of Wire		Weight of Copper Dissolved, Milligrams per Square Decimetre			
From	Up to and including	Ordinary Conductor Cables		Flexible Conductor Cables and Cords (irrespective of whether conductor built in one or more than one operation)	
in.	in.	Other Than T.R.S.	T.R.S.	Other Than T.R.S.	T.R.S.
0·0076	0·018			40	50
0·0181	0·103	30	30	30	30

If the result for one group exceeds the limiting value specified in the table, the test shall be repeated on a fresh group comprising specimens cut from the same wires from which the original defective group was taken, in order to ensure that the failure is not due purely to "end effect."

If this additional group fails to pass the test, the cable represented by this sample may be rejected.

APPENDIX No. 3.

CONDUCTORS FOR FLEXIBLE CABLES (B.S. No. 7, 1953).

(Annealed High-Conductivity Copper).

1	2	3	4	5	6	7	8	9	10	11	12	13
Nominal Area of Conductor	Number of Wires Comprising Conductor, each having a Diameter of :—				Resistance per 1,000 Yards at 20° C. of Conductors given in Column 1, when each Conductor is Comprised of Wires with a Diameter of :—							
					0·010 in.		0·012 in.		0·018 in.		0·029 in.	
	0·010 in.	0·012 in.	0·018 in.	0·029 in.	Standard	Maximum Allowable for Tinned Wires	Standard	Maximum Allowable for Tinned Wires	Standard	Maximum Allowable for Tinned Wires	Standard	Maximum Allowable for Tinned Wires
Sq. in.					ohm.	ohm.	ohm.	ohm.	ohm.	ohm.	ohm.	ohm.
0·01	140	97	—	—	2·334	2·426	2·338	2·432	—	—	—	—
0·0145	195	—	60	—	1·675	1·742	—	—	1·680	1·748	—	—
0·0225	296	—	91	—	1·104	1·148	—	—	1·108	1·153	—	—
0·03	—	266	117	—	—	—	0·853	0·888	0·862	0·900	—	—
0·04	—	368	163	—	—	—	0·617	0·641	0·619	0·643	—	—
0·06	—	557	248	—	—	—	0·407	0·424	0·407	0·424	—	—
0·1	—	—	416	160	—	—	—	—	0·242	0·253	0·238	0·248
0·15	—	—	610	235	—	—	—	—	0·166	0·172	0·162	0·169
0·2	—	—	810	312	—	—	—	—	0·125	0·130	0·122	0·127
0·3	—	—	1248	481	—	—	—	—	0·0808	0·0840	0·0792	0·0824
0·4	—	—	1677	646	—	—	—	—	0·0602	0·0626	0·0590	0·0613
0·5	—	—	2057	792	—	—	—	—	0·0491	0·0510	0·0481	0·0500
0·75	—	—	—	1181	—	—	—	—	—	—	0·0323	0·0336
1·0	—	—	—	1645	—	—	—	—	—	—	0·0232	0·0241

APPENDIX No. 4.

CONDUCTORS FOR FLEXIBLE CORDS (B.S. No. 7, 1953).

(Annealed High-Conductivity Copper).

1	2	3	4	5
Nominal Area of Conductor	Number and Diameter of Wires	Approximate Diameter of Conductor	Resistance per 1,000 yards at 20° C.	
			Standard	Maximum Allowable for Tinned Wires
sq. in.	in.	in.	ohms.	ohms.
0·0006	14/·0076	0·034	40·40	42·03
0·001	23/·0076	0·046	24·59	25·55
0·0017	40/·0076	0·057	14·15	14·71
0·003	70/·0076	0·076	8·08	8·41
0·0048	110/·0076	0·092	5·14	5·34
0·007	162/·0076	0·120	3·49	3·63

APPENDIX No. 5.

COMPARATIVE DIAMETERS AND WEIGHTS OF BRITISH S.W.G. AND AMERICAN B. AND S. WIRE GAUGES.

1	2	3	4	5
No. of Wire Gauge	British S.W.G.		American Brown and Sharpe	
	Diameter Inch	Weight Lb. per 1,000 Yards	Diameter Inch	Weight Lb. per 1,000 Yards
7/0	·500	2270·7	—	—
6/0	·464	1955·5	·580	3054·6
5/0	·432	1695·1	·5165	2422·8
4/0	·400	1453·3	·460	1918·2
3/0	·372	1256·9	·4096	1521·1
2/0	·348	1100·0	·3648	1206·3
1/0	·324	953·49	·3249	956·85
1	·300	817·47	·2893	758·55
2	·276	691·91	·2576	601·72
3	·252	576·81	·2294	476·72
4	·232	488·88	·2043	378·42
5	·212	408·23	·1819	300·00
6	·192	334·83	·1620	238·08
7	·176	281·35	·1443	188·64
8	·160	232·52	·1285	149·44
9	·144	188·35	·1144	118·75
10	·128	148·82	·1019	93·75
11	·116	122·22	·0907	77·84
12	·104	98·24	·0808	59·09
13	·092	76·878	·0720	46·93
14	·080	58·131	·0641	37·22
15	·072	47·086	·0571	29·489
16	·064	37·204	·0508	23·410
17	·056	28·484	·0453	18·523
18	·048	20·927	·0403	14·716
19	·040	14·533	·0359	11·364
20	·036	11·771	·0320	9·262
21	·032	9·301	·0285	7·330

APPENDIX No. 5 (continued).

COMPARATIVE DIAMETERS AND WEIGHTS OF BRITISH S.W.G. AND AMERICAN B. AND S. WIRE GAUGES.

1	2	3	4	5
No. of Wire Gauge	British S.W.G.		American Brown and Sharpe	
	Diameter Inch	Weight Lb. per 1,000 Yards	Diameter Inch	Weight Lb. per 1,000 Yards
22	·028	7·121	·0253	5·796
23	·024	5·232	·0226	4·619
24	·022	4·397	·0201	3·659
25	·020	3·633	·0179	2·909
26	·018	2·943	·0159	2·307
27	·0164	2·443	·0142	1·830
28	·0148	1·990	·0126	1·438
29	·0136	1·680	·0113	1·136
30	·0124	1·397	·0100	·896
31	·0116	1·222	·0089	·716
32	·0108	1·059	·0080	·568
33	·0100	·9083	·0071	·449
34	·0092	·7688	·0063	·358
35	·0084	·6409	·0056	·284
36	·0076	·5246	·0050	·239
37	·0068	·4200	·0045	·176
38	·0060	·3270	·0040	·148
39	·0052	·2456	·0035	·119
40	·0048	·2093	·0031	·085
41	·0044	·1759	·0028	·068
42	·0040	·1453	·0025	·051
43	·0036	·1177	·0022	·040
44	·0032	·0930	·0020	·034
45	·0028	·0712	·00176	·023
46	·0024	·0523	·00157	—
47	·0020	·0363	·00140	—
48	·0016	·0233	·00124	—
49	·0012	·01308	·00099	—
50	·0010	·00908	·00088	—

APPENDIX No. 6.

SOLID AND STRANDED CIRCULAR CONDUCTORS TO B.S. No. 7, 1953.

(Annealed High-Conductivity Copper).

1	2	3	4	5	6	7
Standard Sizes		Number and Diameter of Wires Comprising Conductor	Diameter of Conductor	Resistance per 1,000 yards at 20° C.		
Nominal Area	Calculated Area			Standard	Maximum Allowable for Tinned Wires‡	Standard Sizes Nominal Area
sq. in.	sq. in.	in.	in.	ohms.	ohms.	sq. in.
*0·001	0·000924	3/·020	0·043	26·44	27·50	0·001
*0·001	0·001018	1/·036	0·036	24·01	24·97	0·001
0·0015	0·001521	1/·044	0·044	16·07	16·71	0·0015
0·002	0·001943	3/·029	0·062	12·58	13·08	0·002
0·003	0·002994	3/·036	0·078	8·160	8·406	0·003
†0·003	0·003217	1/·064	0·064	7·596	7·900	0·003
0·0045	0·004546	7/·029	0·087	5·374	5·590	0·0045
0·007	0·007005	7/·036	0·108	3·488	3·593	0·007
0·01	0·01046	7/·044	0·132	2·335	2·405	0·01
0·0145	0·01462	7/·052	0·156	1·672	1·722	0·0145
0·0225	0·02214	7/·064	0·192	1·103	1·137	0·0225
0·03	0·02835	19/·044	0·220	0·8618	0·8876	0·03
0·04	0·03960	19/·052	0·260	0·6171	0·6355	0·04
0·06	0·05999	19/·064	0·320	0·4073	0·4195	0·06
0·1	0·1009	19/·083	0·415	0·2422	0·2494	0·1
0·15	0·1478	37/·072	0·504	0·1654	0·1703	0·15
0·2	0·1964	37/·083	0·581	0·1245	0·1281	0·2
0·3	0·3024	37/·103	0·721	0·08080	0·08322	0·3
0·4	0·4064	61/·093	0·837	0·06013	0·06193	0·4
0·5	0·4985	61/·103	0·927	0·04902	0·05049	0·5
0·75	0·7435	91/·103	1·133	0·03286	0·03385	0·75
1·0	1·0376	127/·103	1·339	0·02355	0·02425	1·0

* These sizes are for fittings wires only.

† This size is for use in railway signalling circuits only.

‡ For tinned hard drawn copper conductors the resistance quoted in Column 6 should be increased by 2½%.

APPENDIX No. 7.

CHARACTERISTICS OF DIELECTRICS.

	Specific Resistance (megohms/cm.^{3}) = R × 10^6 R =	Permittivity (S.I.C. or Dielectric Constant) k	Dielectric Strength kV/cm.	Power Factor at 50 C/s	Specific Gravity (Approximate)
Air	Approaching Infinity	1·0	38	—	—
Paraffin Wax ...	3,000,000	2·0 to 2·2	125	0·0003	0·90
Rubber, Vulcanised	Up to 10,000	3·5 to 5·0	100 to 250	0·02	1·2 to 1·6
Bitumen	100	3·0 to 4·0	130	0·008	1·05
Polyethylene ...	300,000	2·3	400	0·0003	0·92 to 0·94
P.V.C.	10 (approx.)	7·0	250	0·12	1·3 to 1·4

APPENDIX No. 8.

ELECTRICAL RESISTIVITY OF THE METALLIC COMPONENTS OF ELECTRIC CABLES.

Material	Resistivity at 20° C. ohms/sq.$^{m}/_{m}$/metre	Temperature Coefficient per ° C. from 20° C.
High Conductivity Annealed Copper	0·01724	0·00393
Hard Drawn Copper ...	0·0178	0·0038
Steel Steel Wire Armour ... Steel Tape Armour ...	 0·138 0·128	 0·005 0·004
Lead (and Lead Alloys) ...	0·215	0·004
Aluminium (Pure)	0·0284	0·0035
Silmalac Typical Composition (0.45% Magnesium 0·55% Silicon 0·30% Iron 98·5% (Min) Aluminium)	0·031	0·0035
Everdure Typical Composition (96·1% Copper 0·74% Manganese 2·78% Silicon 0·38% Other metals including Tin)	0·246	0·003

APPENDIX No. 9.

DEFINITION OF CERTAIN TERMS USED IN CABLE TECHNOLOGY.

Term	*Definition*
Armouring	A metal covering usually applied in the form of tape or wire, intended to protect a cable from mechanical damage.
Bedding	Of an armoured cable. Layer(s) of fibrous material which may or may not be permeated with waterproof compound applied to the cable beneath the armouring.
Braiding	A plaited protective covering of a cable generally of fibrous material.
Cable	A length of single insulated conductor (solid or stranded) or two or more conductors each provided with its own insulation which are laid up together. The insulated conductor(s) may or may not be provided with an overall mechanical protective covering.
Concentric Cable ...	A cable containing two or more separate conductors arranged concentrically with insulation between them. Unless otherwise qualified, the term denotes a cable consisting of two conductors only.
Conductor	Of a cable or core. The conducting portion consisting of a single wire, or a group of wires assembled together and in contact with each other or connected in parallel.
Core	Of a cable. A single conductor with its insulation but not including any mechanical protective covering.
Cross-Sectional Area ...	The sum of the cross-sectional areas of the component wires of the conductor of a cable, that of each wire being measured perpendicular to its individual axis.
Earth Shield	A metal sheath immediately under and in contact with the lead sheath of a cable.
Electrolytic Wire Bar ...	A wire bar composed of electrolytically refined copper.
Flexible Cable	A cable containing one or more cores, each formed of a group of wires, the diameters of the cores and of the wires being sufficiently small to afford flexibility.
Flexible Cord (Flex.) ...	A flexible cable having conductors of small cross-sectional area., Two flexible cords twisted together are known as *Twin Flexible Cord*.
Insulation	That part of a cable which serves to insulate the conductor.

Term	*Definition*
Lay Ratio	The ratio of the axial length of a complete turn of the helix formed by the core of a cable, or the wire of a stranded conductor, to the mean diameter of the helix.
Length of Lay	The axial length of one complete turn of the helix formed by the core, in the case of a cable, or of the wire, in the case of a stranded conductor.
Lead Covered Cable ...	A cable provided with a lead sheath for the purpose of excluding moisture from the conductors and insulation thereof, such sheath consisting either of commercially pure lead or alternatively of pure lead to which a small percentage of rare metals has been added for hardening purposes.
Proofed Tape	A tape applied to the insulation of rubber insulated cables, and composed of cotton cloth coated with a rubber compound.
Rated Voltage	The voltage for which the insulation (dielectric) of a cable is designed.
Reinforcement	Metal wires, strips, or tapes applied for the purpose of reinforcing the lead sheath against expansion under internal pressure.
Screen	A metal tape or metallised paper tape applied over the insulation of a cable core to form an electrostatic screen.
Serving	Of an armoured or metal sheathed cable. Layer(s) of fibrous material, permeated with waterproof compound applied to the exterior of a cable.
Stranded Conductor ...	A conductor made up of a number of wires twisted together. When the conductor consists of more than one layer, alternate layers are twisted in opposite directions.
Stress	Electric stress.
Tough Rubber Sheathing	A sheathing used on an insulated conductor to form an outer protective covering of tough rubber composed of rubber mixed with hardening substances and suitably vulcanised to make it waterproof and resistant to decay, mechanical abrasion, acids, alkalis and other corrosive materials.
Triple Concentric Cable ...	A concentric cable containing three conductors.

APPENDIX No. 10.

SUMMARY OF PRINCIPAL BRITISH STANDARD* SPECIFICATIONS RELATING TO V.R. INSULATED CABLES.

British Standard (No., Year of Issue)	Title	Voltage Range
B.S. 7, 1953 ...	Rubber Insulated Cables and Flexible Cords for Electric Power and Lighting.	250 Volt-11 kV (inclusive)
B.S. 443, 1939 ...	Testing of zinc coating on galvanised wires.	—
B.S. 708, 1950 ... (*Under Revision*).	Trailing Cables for Mining purposes.	250 Volt and 660 Volt.
B.S. 801, 1953 ...	Lead and Lead Alloys for Cable Sheathing.	—
B.S. 883, 1949 ... (*Under Revision*).	Cables and Flexible Cords for Electrical Equipment of Ships.	660 Volt-6·6 kv Paper Cables. 660 Volt-6·6 kV V.C. Cables. Also range of V.I.R. and P.V.C. Insulated Cables and Mineral Insulated Cables.
B.S. 903, 1950 ...	Testing Vulcanised Rubber.	—
B.S. 937, 1940 ...	Flexible Cords for Miners' Cap Lamps.	—
B.S. 1116, 1943 ...	Flexible Trailing Cables for Quarries and Metalliferous Mines.	660 Volts and 3,300 Volts.
B.S. 1442, 1948 ... (*Under Revision*).	Galvanised Mild Steel Wire for Armouring Cables.	—
B.S. 2008, 1953 ...	Wire Armoured Cables (Vulcanised Rubber Insulated) for Collieries.	250, 660 and 3,300 Volts.

*Copies of all British Standards may be purchased from the British Standards Institution, 2 Park Street, London, W.1.

Complete sets of Standards are also maintained for reference purposes by a number of Public Libraries and Colleges in the British Isles.

APPENDIX No. 11.

LEAD AND LEAD ALLOYS FOR SHEATHING CABLES.

Lead or Lead Alloy	Composition (Percentage by Weight)						Lead Including Impurities	Character	* Endurance Limit Tons P.S.I. (Lb. P.S.I.)	Remarks
	Tin		Antimony		Cadmium					
	Min.	Max.	Min.	Max.	Min.	Max.				
Pure Lead	—	—	—	—	—	—	—	Very Pliable	± 0·18 (± 403·2)	For particular application where a very pliable sheath is required and poor fatigue resistance may be tolerated.
A	1·8	2·2	—	—	—	—	97·8 to 98·2%	Hard	± 0·40 (± 896·0)	For house and ship wiring. It is resistant to abrasion and does not age harden. Has been largely superseded by alloy E.
B	—	—	0·8	0·9	—	—	99·1 to 99·2%	Hard	± 0·6 (± 1344·0)	This is an economical alloy very much used for cable sheaths—it is fairly soft after extrusion but develops considerable hardness on ageing. It is used for power and aerial cables and positions where vibration is serious.
C	0·35	0·45	—	—	0·12	0·18	99·37 to 99·53%	Soft	± 0·35 (± 784·0)	This alloy was preferred by the Admiralty for ship wiring and is easier to install than B. It has a high fatigue resistance and remains permanently soft.
D	—	—	0·45	0·55	0·2	0·3	99·15 to 99·35%	Very Hard	± 0·74 (± 1657·6)	For use where vibration is severe and persistent. It has a high fatigue resistance and age hardens. Its stiffness precludes its use where ductility is important.
E	0·35	0·45	0·15	0·25	—	—	99·3 to 99·5%	Soft	± 0·41 (± 918·4)	A wartime substitute for alloys A and C which is now tending to be used as a permanent alternative to these two alloys.

* Taken as the range of stress which will cause failure after 10 million reversals.

APPENDIX No. 12.

CAPACITY OF CONDUITS (250-Volt Grade Cables).

Maximum capacity of conduits (B.S. 31) for the similtaneous drawin-in of 250-volt grade rubber-insulated and taped and braided cables to Table 22 of B.S. 7 (1953), or p.v.c.-insulated cables to Table 14 of B.S. 2004 (1953). (See I.E.E. Regulation 218 (B)).

Size of Conduit			Light-Gauge		Heavy-Gauge					
			$\frac{5}{8}$ in.	$\frac{3}{4}$ in.	$\frac{5}{8}$ in.	$\frac{3}{4}$ in.	1 in.	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.	2 in.
Conductor of Cable		Approximate Overall Diameter of Taped and Braided Cable	Maximum Number of Rubber-Insulated and Taped and Braided or P.V.C.-Insulated Cables							
Nominal Cross-Sectional Area	Number and diameter (in) of Wires									
in.^{2}		in.								
0·0015	1/·044	0·150	6	8	5	7	13	20	—	—
0·002	3/·029	0·165	5	7	4	6	13	20	—	—
0·003	3/·036	0·180	4	6	3	5	10	16	—	—
0·0045	7/·029	0·190	4	5	3	4	9	13	—	—
0·007	7/·036	0·220	2	4	2	3	7	10	14	—
0·01	7/·044	0·255	—	—	—	2	5	8	11	—
0·0145	7/·052	0·290	—	—	—	—	4	7	9	—
0·0225	7/·064	0·325	—	—	—	—	3	5	7	12
0·03	19/·044	0·365	—	—	—	—	2	4	6	9
0·04	19/·052	0·415	—	—	—	—	—	3	4	6
0·06	19/·064	0·485	—	—	—	—	—	—	3	5

For groups of cable, other than provided for above, the number and size of the cables installed shall be such that a space factor of 40% is not exceeded.

Refer "Space Factor in Wiring," by J. Johnson, *Electrical Times*, 5th January, 1956, for detailed examples showing a method of computing trunking and conduit capacities.

APPENDIX No. 13.

COMPUTING CONDUCTOR SIZES.

Cable enquiries can be divided into two main classes—those in which the purchaser has decided on the conductor size and type of cable required, and the second category in which the cable maker is requested to make recommendations.

Dealing with the first type of enquiry, essential information relating to rubber and thermoplastic insulated cables is summarised by :—

(*a*) Number of reels or coils required, and the total yardage.

(*b*) Conductor section, *e.g.*, 0·0225 sq. inch or 7/·064 strand.

(*c*) Number of cores.

(*d*) Working voltage (phase-to-phase, or phase-to-earth).

(*e*) Type of finish (lead sheathed, T.R.S., etc.).

(*f*) If steel armoured, state single or double wire armour (S.W.A. or D.W.A.)—or double steel tape armour (D.S.T.A.).

(*g*) If above 660 Volt state whether the system is earthed (E.) or unearthed (U.E.).

The second type of enquiry is that in which the manufacturer is requested to make recommendations.

In the absence of a detailed cable specification, the following is a guide to the data required.

(*a*) Type of supply system, *e.g.*, 250 volt d.c., 2 wire, or 400/430, 3 phase, 4 wire a.c. supply ; or 6,600 volt, 3 phase a.c. system, centre point earthed, etc.

(*b*) Power load, current per phase (amp.), or load in kilovolt amp. (kVA), kilowatts (kW), stating power factor or horse-power (h.p.), stating also the power factor and efficiency of the motor (if known).

(*c*) Voltage drop, state maximum permissible figure, and whether phase to phase or phase to neutral voltage.

(*d*) Method of installation.

(*e*) Nature of loading ; if the load is intermittent and the most favourable current rating is required give full particulars of the load cycle, *i.e.*, average load 250 amp. for eight hours, no load 16 hours, six days per week, etc.

Line Current.

The line current can be computed from the following formulae depending on the type of load specified.

Given kilowatts (kW)

$$\text{Current (I) in amps.} = \frac{\text{KW} \times 1{,}000}{\text{Line Volts} \times \text{Power Factor} \times 1{\cdot}732} \quad - \quad - \quad (1)$$

Given kilovolt amps. (kVA)

$$\text{Current (I) in amps.} = \frac{\text{kVA} \times 1{,}000}{\text{Line Volts} \times 1{\cdot}732} \quad - \quad - \quad - \quad - \quad (2)$$

Given Horse Power (H.P.)

$$\text{Current (I) in amps} = \frac{\text{H.P.} \times 746}{\text{Line Volts} \times 1{\cdot}732 \times \text{Efficiency} \times \text{Power Factor}} \quad (3)$$

APPENDIX No. 13 (continued).

Having obtained the current (amps.), the required conductor size is obtained from Table No. 15, depending on the grouping and method of installation adopted.

Approximate full load currents for D.C. and A.C. motors of standard brake horse power are given in Appendix No. 14.

Voltage Drop.

Regulation 204 of the I.E.E. Regulations limits the voltage drop at normal full load in lighting circuits to 1 volt + 2% of the supply voltage between consumers' terminals (or main busbars) and any point on the installation. The approximate voltage drop in average circuits such as lighting and domestic heating loads may be found as follows, neglecting increased resistance due to temperature rise.

(1) D.C. and Single Phase A.C. Two-Wire Circuits.

V.D. = Current (amps.) × total resistance of cables, lead and return.

$$= 2\,I\,R \quad - - - - - - - - - - - - \quad (4)$$

Where I = Current

R = Resistance of a single conductor (lead only), *e.g.*, to compute the voltage drop with a 15 amp. load on 60 ft. run of two single 7/·044 cables;

Maximum resistance 7/·044 conductor at 20° C. = 2·405 ohms per 1,000 yard length (refer Appendix No. 6, Col. 6).

Total resistance of 60 ft. run = 2R

$$\text{Total resistance of 60 ft. run} = \frac{2{\cdot}405 \times 60 \times 2}{3 \times 1{,}000} = 0{\cdot}0962$$

Voltage Drop (2IR) = 15 × 0·0962 = 1·44 Volts.

As an approximate correction for temperature, increase the result by 15% to allow for the temperature limits permitted by the I.E.E. Regulations, viz., Ambient Air Temperature 90° F. (32·2° C.). Permissible temperature rise for V.R. and for P.V.C. insulated cables—30° F. (16·7° C.).

(2) Three-Phase Circuits.

V.D. = 1·732 × I R - - - - - - - - - (5)

Where I = Line current per phase

R = Ohmic resistance of one core only.

For the case of large three core cables carrying heavy loads the internal reactance of the cable must also be allowed for.

APPENDIX No. 14.

CURRENT FOR D.C. AND A.C. MOTORS.

Approximate Full Load Current (in Amperes) per Line or per Phase for Motorsof Average Efficiency and Power-Factor.

B.H.P.	D.C. Voltage					A.C. (Three-Phase Voltage)					
	110	220	230	460	500	200	220	346	400	440	550
1	10·0	5·0	4·8	2·4	2·2	3·6	3·3	2·1	1·8	1·7	1·3
2	18·0	9·0	8·6	4·3	4·0	6·8	6·2	4·0	3·4	3·1	2·5
3	26·0	13·0	12·0	6·2	5·7	9·6	8·8	5·6	4·8	4·4	3·5
4	34·0	16·7	16·0	8·0	7·4	12·4	11·3	7·2	6·2	5·7	4·5
5	42·0	21·0	20·0	10·0	9·2	15·2	13·8	8·8	7·6	6·9	5·5
7½	60·0	30·0	29·0	14·0	13·0	22·0	20·0	12·7	11·0	10·0	8·0
10	80·0	40·0	38·0	19·0	18·0	28·6	26·0	16·5	14·3	13·0	10·4
12½	100·0	50·0	48·0	24·0	22·0	35·2	32·0	20·5	17·6	16·0	13·2
15	117·0	59·0	56·0	28·0	26·0	42·0	38·0	25·0	21·0	19·0	16·0
20	154·0	77·0	74·0	36·0	34·0	56·0	51·0	33·0	28·0	26·0	21·0
25	192·0	96·0	92·0	46·0	42·0	70·0	64·0	41·0	35·0	32·0	26·0
30	227·0	114·0	109·0	55·0	50·0	82·0	75·0	48·0	41·0	38·0	30·0
40	300·0	150·0	143·0	72·0	66·0	112·0	102·0	65·0	56·0	51·0	41·0
50	375·0	187·0	179·0	89·0	82·0	138·0	126·0	80·0	69·0	63·0	50·0
60	447·0	223·0	214·0	107·0	98·0	166·0	151·0	96·0	83·0	75·0	60·0
75	560·0	280·0	268·0	134·0	123·0	206·0	188·0	119·0	103·0	94·0	75·0
100	740·0	370·0	354·0	177·0	163·0	276·0	256·0	160·0	138·0	126·0	100·0
150	—	550·0	526·0	264·0	242·0	412·0	374·0	238·0	206·0	187·0	150·0
200	—	—	—	349·0	322·0	548·0	498·0	317·0	274·0	249·0	199·0

APPENDIX No. 15.

THERMAL CLASSIFICATION OF INSULATING MATERIALS.

On the basis of equivalent thermal endurance an agreed classification has been internationally accepted and recorded in Publication No. 34 of the International Electrochemical Commission as follows :—

Table No. 1.

Thermal Endurance of Insulating Material.

(International Classification).

Class O	Cotton, silk, paper and similar organic materials (without impregnation or immersion in oil).
Class A	Cotton, silk, paper and similar organic materials when impregnated or immersed in oil, also enamel applied to enamelled wire.
Class B	Mica and asbestos and similar inorganic materials, in built up form combined with binding cement.
Class C	Mica, without binding cement, porcelain glass quartz and other similar materials.

In addition to above classification American engineers have adopted a further group designated Class H which consists of :—

(1) Mica, asbestos fibreglass and similar inorganic materials in built-up form with binding substances composed of silicone compounds, or materials with equivalent properties, and

(2) Silicone compounds in rubbery or resinous forms or materials with equivalent properties.

The American (A.I.E.E.) standards also specifies limiting insulation temperatures as follows :—

Class O, 90° C. ; Class A, 105° C. ; Class B, 130° C. ; Class C. no specified limit, and Class H, 180° C.

The thermal classifications referred to have been under review in many countries for some time.

References.

(1) W. Obvager, "The Present Position in the Thermal Rating and Classification of Insulating Materials," *E.u.M.*, Vol. 70, pp. 247-250, 1st June, 1953.

(2) R. Snadow, "Insulating Materials. Their Thermal Classification," *Electrical Times*, Vol. 123, No. 3198, 19th February, 1953.

APPENDIX No. 16.

TEMPORARY RELAXATION IN CURRENT RATINGS OF SMALL V.R., P.V.C. PAPER AND V.C. CABLES FOR WIRING OF BUILDINGS.

Arising out of a report (Economy of Building Materials) prepared by an inter-departmental committee set up by the Ministry of Works a proposal was made that cable ratings should be reviewed in the interests of economy.

The Council of the Institution of Electrical Engineers has therefore decided to issue a temporary relaxation to the 12th Edition of the I.E.E. Regulations incorporating higher current ratings for cables with conductors up to 7/·029—the revised ratings which came into effect from 15th December, 1952, are given below.

Nominal Area of Conductor	Number and Diameter of Wires	Rating for D.C. or A.C. (Single or Three-Phase)	
		Not more than 4 single-core cables, 2 twin or concentric cables, one three-core cable	Not more than 8 single-core cables, 4 twin or concentric cables, two three-core cables
1	2	3	4
Sq. inch	Inch	Amps.	Amps.
0·0015	1/·044	5	5
0·002	3/·029	10	8
0·003	3/·036	15	10
0·0045	7/·029	20	15

N.B.—Where advantage is taken of the increased current ratings in above table, care should be taken to ensure that lighting fittings and accessories of appropriate size are used, as it cannot be assumed that an accessory will be capable of dealing with the increased current permitted in the cable.

A.E.S.D. Printed Pamphlets and Other Publications in Stock.

An up-to-date list of A.E.S.D. pamphlets in stock is obtainable on application to the Editor, *The Draughtsman*, Onslow Hall, Little Green, Richmond, Surrey.

A similar list is also published in *The Draughtsman* twice a year.

Readers are asked to consult this list before ordering pamphlets published in previous sessions.

List of A.E.S.D. Data Sheets

1. Safe Load on Machine-Cut Spur Gears.
2. Deflection of Shafts and Beams. } Connected.
3. Deflection of Shafts and Beams (Instruction Sheet). }
4. Steam Radiation Heating Chart.
5. Horse-Power of Leather Belts, etc.
6. Automobile Brakes (Axle Brakes). } Connected.
7. Automobile Brakes (Transmission Brakes). }
8. Capacities of Bucket Elevators.
9. Valley Angle Chart for Hoppers and Chutes.
10. Shafts up to $5\frac{1}{2}$ inch diameter, subjected to Twisting and Combined Bending and Twisting.
11. Shafts, $5\frac{3}{4}$ to 26 inch diameter, subjected to Twisting and Combined Bending and Twisting.
12. Ship Derrick Booms.
13. Spiral Springs (Diameter of Round or Square Wire).
14. Spiral Springs (Compression).
15. Automobile Clutches (Cone Clutches).
16. ,, ,, (Plate Clutches).
17. Coil Friction for Belts, etc.
18. Internal Expanding Brakes. Self-Balancing Brake Shoes (Force Diagram). } Connected
19. Internal Expanding Brakes. Angular Proportions for Self-Balancing. }
20. Referred Mean Pressure Cut-Off, etc.
21. Particulars for Balata Belt Drives.
22. $\frac{7}{8}$" Square Duralumin Tubes as Struts.
23. 1" ,, ,, ,, ,,
24. $\frac{3}{4}$" Square Steel Tubes as Struts (30 ton yield).
25. $\frac{7}{8}$" ,, ,, ,, (30 ton yield).
26. 1" ,, ,, ,, (30 ton yield).
27. $\frac{3}{4}$" ,, ,, ,, (40 ton yield).
28. $\frac{7}{8}$" ,, ,, ,, (40 ton yield).
29. 1" ,, ,, ,, (40 ton yield).
30. Moments of Inertia of Built-up Sections (Tables). } Connected.
31. Moments of Inertia of Built-up Sections (Instructions and Examples). }
34. Capacity and Speed Chart for Troughed Band Conveyors.
35. Screw Propeller Design (Sheet 1, Diameter Chart). } Connected.
36. ,, ,, ,, (Sheet 2, Pitch Chart). }
37. ,, ,, ,, (Sheet 3, Notes & Examples). }
38. Open Coil Conical Springs.
39. Close Coil Conical Springs.
40. Trajectory Described by Belt Conveyors (Revised, 1949).
41. Metric Equivalents.
42. Useful Conversion Factors.
43. Torsion of Non-Circular Shafts.
44. Railway Vehicles on Curves.
46. Coned Plate Development.
47. Solution of Triangles (Sheet 1, Right Angles).
48. Solution of Triangles (Sheet 2, Oblique Angles).
49. Relation between Length, Linear Movement and Angular Movement of Lever (Diagram and Notes).
50. ,, ,, ,, ,, ,, ,, (Chart).
51. Helix Angle and Efficiency of Screws and Worms.
52. Approximate Radius of Gyration of Various Sections.

53. Helical Spring Graphs (Round Wire).
54. ,, ,, ,, (Round Wire).
55. ,, ,, ,, (Square Wire).
} Connected.

56. Relative Value of Welds to Rivets.
58. Graphs for Strength of Rectangular Flat Plates of Uniform Thickness.
59. ,, Deflection ,, ,, ,, ,, ,,
61. Deflection of Leaf Spring.
62. Strength of Leaf Spring.
63. Chart Showing Relationship of Various Hardness Tests.
64. Shaft Horse-Power and Proportions of Worm Gear.
65. Ring with Uniform Internal Load (Tangential Strain)
66 ,, ,, ,, ,, (Tangential Stress)
} Connected.

67. Hub Pressed on to Steel Shaft. (Maximum Tangential Stress at Bore of Hub).
68. Hub Pressed on to Steel Shaft. (Radial Gripping Pressure between Hub and Shaft).
69. Rotating Disc (Steel) Tangential Strain.
70. ,, ,, ,, Stress.
} Connected.

71. Ring with Uniform External Load, Tangential Strain.
72. ,, ,, ,, ,, ,, Stress.
} Connected.

73. Viscosity Temperature Chart for Converting Commercial to Absolute Viscosities.
74. Journal Friction on Bearings.
75. Ring Oil Bearings.
} Connected.

76. Shearing and Bearing Values for High Tensile Structural Steel Shop Rivets, in accordance with B.S.S. No. 548/1934.
78. Velocity of Flow in Pipes for a Given Delivery.
79. Delivery of Water in Pipes for a Given Head.
} Connected.

80. (See No. 105).
81. Involute Toothed Gearing Chart.
83. Variation of Suction Lift and Temperature for Centrifugal Pumps.
89. Curve Relating Natural Frequency and Deflection.
90. Vibration Transmissibility Curved or Elastic Suspension.
91. Instructions and Examples in the Use of Data Sheets, Nos. 89 and 90.
} Connected.

92. Pressure on Sides of Bunker.
93-4-5-6-7. Rolled Steel Sections.
98-9-100. Boiler Safety Valves.
102. Pressure Required for Blanking and Piercing.
103. Punch and Die Clearances for Blanking and Piercing.
104. Nomograph for Valley Angles of Hoppers and Chutes.
105. Permissible Working Stresses in Mild Steel Struts with B.S. 449, 1948.
106. Compound Cylinder (Similar Material) Radial Pressure of Common Diameter (D1).

(Data Sheets are 3d to Members, 6d to others, post free).

Orders for Pamphlets and Data Sheets to be sent to the Editor, *The Draughtsman*, cheques and orders being crossed "A.E.S.D."